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Unlocking environmental harmony through export earnings: exploring the impact of remittances and infrastructure growth

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Introduction: This study investigates the complex relationship between economic growth, remittances (REM), export earnings (EEs), infrastructural development (IFD), and environmental sustainability (ES) in Bangladesh over the period from 1990 to 2020. Framed within the context of the Environmental Kuznets Curve (EKC) hypothesis, the research explores how these factors influence environmental outcomes and contributes to ongoing discussions on sustainable development.

Methods: Utilizing advanced time-series modeling techniques, including autoregressive distributed lag (ARDL) and nonlinear ARDL (NARDL), this study applies unit root tests and co-integration analysis to examine the data. These methods allow for a detailed assessment of both short- and long-term relationships between the variables in question.

Results: The findings confirm the EKC hypothesis, showing that economic growth initially leads to increased carbon emissions and environmental degradation, but further development contributes to environmental improvements. Remittances, however, significantly exacerbate carbon emissions and ecological degradation. On the other hand, technological innovation (TI) demonstrates a negative association with carbon emissions and ecological footprint (EF), highlighting its potential in supporting sustainable development. The impacts of export earnings and infrastructural development on environmental sustainability are mixed, with infrastructural growth in particular linked to environmental degradation.

Discussion: The study's results underscore the importance of targeted policy interventions to balance economic growth with environmental sustainability. Policymakers should focus on mitigating the environmental impacts of remittance inflows and fostering technological innovation to achieve the Sustainable Development Goals (SDGs). While export earnings and

Abbreviations: ARDL, autoregressive distributed lag; BPG, Breusch–Pagan–Godfrey; CO_2, carbon dioxide; CS-ARDL, cross-sectionally augmented autoregressive distributed lag; DCP, domestic credit to private sector; EKC, environmental Kuznets curve; EE, export earning; EF, ecological footprint; ES, environmental sustainability; FDI, foreign direct investment; IFD, infrastructural development; J-B, Jarque–Bera; NARDL, nonlinear autoregressive distributed lag; REM, remittances; TI, technological innovation; TY, Toda and Yamamoto; VAR, vector autoregression.

infrastructural development play critical roles in economic progress, their environmental implications require careful management to ensure long-term sustainability.

KEYWORDS

remittances, environmental sustainability, environmental Kuznets curve, autoregressive distributed lag, nonlinear autoregressive distributed lag

1 Background of the study

Prioritizing environmental sustainability (ES, hereafter) is of utmost importance for Bangladesh's economic advancement as it strives to attain the Sustainable Development Goals (SDGs) (Hasan et al., 2023; Hasan et al., 2022); thus, attaining these global objectives requires a careful equilibrium between promoting economic growth and protecting the environment (Hasan et al., 2019; Uddin and Jeong, 2021). Bangladesh encounters distinctive obstacles, including its susceptibility to climate change and the imperative of offering assistance to a densely populated nation. The importance of ES cannot be overstated as it directly impacts not only the global ecosystem but also the long-term stability and resilience of Bangladesh's economy. Considering the urgent issues related to air and water pollution, deforestation, and climate change, it is crucial to integrate sustainable practices into economic policies. Emphasizing sustainability not only protects the country's diverse wildlife but also has a significant impact on enhancing the wellbeing of its population, addressing challenges like poverty, hunger, and health. These aspects play a crucial role in the attainment of the SDGs. Advocating for ES is of utmost importance for Bangladesh as it brings about benefits to the ecosystem and plays a significant role in driving economic growth and fulfilling global obligations.

In recent years, Bangladesh has experienced a significant increase in remittances, which have played a vital role in bolstering its economy (Amit and Kafy, 2024; Shah and Wani, 2024). These financial inflows from overseas workers have become an essential source of income for the country. Simultaneously, the nation has been diligently striving to boost its export earnings (EEs), enhance its infrastructure, and address pressing concerns regarding environmental sustainability. Understanding the intricate connections between these components is crucial for crafting policy frameworks that foster economic growth while also guaranteeing environmental sustainability. The impact of remittances (REM) on ES can be both positive and negative. Existing literature has suggested that remittances have the potential to mitigate environmental pollution, whereas economic growth may contribute to higher levels of pollution (Dash et al., 2024; Mills, 2023; Li et al., 2022a). REM have the potential to be valuable sources of funding for climate change adaptation and resilience building in developing nations (Ahmad et al., 2022). The ecological footprint (EF) in certain countries can be influenced by remittance inflows, with their impact on environmental quality being shaped by factors like technical innovation (TI) and financial development (Sunge and Mudzingiri, 2023; Maduekwe and Adesina, 2022; Yang et al., 2021). It is crucial to ensure the appropriate allocation of REM in order to achieve environmental sustainability. Nevertheless, REM often lack a focus on sustainable development and may even contribute to environmental degradation (ED) (Ahmad et al., 2019a; Choumert et al., 2015).

Adopting sustainable practices may result in cost savings due to their lower energy and resource requirements, greater efficiency, and decreased waste generation (Sharma et al., 2022). Additionally, sustainable practices enable firms to adhere to environmental and social regulations in several countries, thus avoiding potential difficulties. In 2018, the United States had a significant range of sustainable exports, such as waste and scrap materials, air pollution control equipment, environmental monitoring and analysis equipment, water treatment technology, and renewable energy technologies (Trinh et al., 2022). Improving the caliber of exports via the adjustment of the energy composition and transportation techniques may foster a more environmentally sustainable condition (Cutcu et al., 2023). Wang X. et al. (2023) postulated that incorporating sustainable practices in the supply chain may effectively reduce the ecological impact and result in financial benefits. Moreover, Henk (1999) revealed that enforcing environmental regulations may have a significant impact on reducing the export of dangerous items and encouraging the export of ecologically sustainable commodities from developing countries. Consequently, EEs may greatly contribute to the attainment of enduring environmental sustainability. Utilizing sustainable goods can have favorable effects on several fronts, including safeguarding the environment, optimizing the use of natural resources, promoting economic diversification, fostering employment opportunities, and alleviating poverty in economically disadvantaged rural regions of developing nations (Huang and Wu, 2022; Zhou et al., 2022). Environmental rules may have an effect on export commerce, with both favorable and unfavorable consequences. Multiple studies have shown that the enforcement of environmental standards may significantly enhance the expansion of export commerce (Wang S. et al., 2023; Khan et al., 2023; Damrah et al., 2022). Moreover, the implementation of efficient environmental legislation may stimulate innovation and compel businesses to improve their goods, thus enhancing their comparative advantages and overall competitiveness (Sharma et al., 2022). Wan et al. (2022) showed that the enforcement of stringent environmental restrictions may reduce the competitive advantage of certain goods.

The study is based on the recognition that these essential components—remittances, export earnings, infrastructural development, and environmental sustainability—are interconnected in a complex way. As Bangladesh undergoes economic transformations, it is essential to comprehend the impact of REM on export earnings, their role in infrastructure development, and the subsequent implications for environmental sustainability. By conducting a thorough analysis of these interconnections, the study seeks to provide valuable insights that can assist decision-makers, scholars, and other interested individuals in comprehending the potential synergies or conflicts that emerge when reconciling economic growth and environmental preservation.

The findings of this study hold significant implications for the formulation of policies in Bangladesh through the support of evidence-based insights into the intricate connections among remittances, export profits, infrastructure development, and environmental sustainability. The study aims to offer guidance to policymakers in promoting strategies that successfully balance economic development and environmental conservation. This objective aligns with Bangladesh's dedication to achieving the Sustainable Development Goals. Furthermore, the findings of the study could have a significant impact on investor confidence, encouraging the adoption of a comprehensive approach that attracts investments from companies looking for ethical and environmentally conscious business environments. From a technical standpoint, this study helps uncover intricate connections and provides a foundation for future investigations. The global importance of this study extends to emerging economies, offering insights that could help countries facing similar challenges in their pursuit of fair and sustainable development.

The study aims to answer the following research questions through empirical assessment:

RQ1. To what extent does the environmental Kuznets curve (EKC) theory apply in Bangladesh in relation to remittances, export earnings, and infrastructural development?
RQ2. What are the implications of remittances, export earnings, and infrastructural development on environmental sustainability in Bangladesh?
RQ3. How can the nexus between remittances, export earnings, infrastructural development, and environmental sustainability in Bangladesh be further strengthened or improved?

This study seeks to address three significant research gaps, contributing to the existing body of knowledge by providing a more comprehensive understanding of the intricate connections between remittances, export earnings, infrastructural development, and ES in Bangladesh.

First, this study aims to fill a crucial research gap by offering a thorough understanding of how remittances, export earnings, infrastructural development, and ES interact in the unique context of Bangladesh. Previous research often focused on isolated aspects, neglecting the complex interrelationships between these factors. This study seeks to offer a comprehensive analysis, emphasizing the interconnections and potential trade-offs, to provide researchers and policymakers with a more holistic viewpoint.

Second, many studies have extensively explored the impact of REM and export earnings on economic development. Unfortunately, there is a significant dearth of research that offers policymakers precise direction on crafting strategies that achieve a harmonious equilibrium between economic growth and environmental sustainability. This study seeks to address a gap in current research by providing evidence-based findings that can inform policy decisions. It presents a clear pathway to achieve sustainable development goals by integrating remittances, export earnings, and infrastructural development while also considering the significance of environmental sustainability.

Third, this study also provides a valuable contribution to addressing a significant research gap that is relevant on a global scale. Although existing studies have examined economic development and ES in various countries, there is a need for research that transcends national boundaries and provides insights applicable to a broader array of developing economies. This study offers valuable insights and lessons that can be applied to other countries grappling with similar challenges, making it a noteworthy contribution to the field of global sustainable development.

The remainder of this paper is structured as follows: Section 2 deals with hypothesis construction and a survey of pertinent studies; the data and methods of the study are explained in Section 3; the estimation and interpretation of empirical models are given in Section 4; study findings, discussion, and policy implications based on the findings are reported in Section 5; and the conclusion and policy suggestions are given in Section 6.

2 Literature review, hypothesis development, and research gap

2.1 Remittances and environmental sustainability

Lin and Qamruzzaman (2023) and JinRu et al. (2023) exposed a significant correlation between REM and CO_2 emissions, which discovered an intriguing mechanism of interaction, where households that receive REM have a tendency to invest in indulgent items like new vehicles and home equipment that, in turn, result in greater fuel combustion and energy consumption, which ultimately leads to an increase in carbon emissions. Li et al. (2022b) discovered that the increase in REM had a detrimental effect on the environmental quality in India. Dash et al. (2024) revealed that REM have a positive influence on the living conditions of households. Consequently, these households have a tendency to buy items that consume a significant amount of energy, resulting in an increase in CO_2 emissions. The literature survey highlights the significance of acquiring a thorough comprehension of the link between REM and CO_2 emissions. It emphasizes the importance of considering the specific situations and policy actions taken in different countries. Furthermore, REM frequently lack a strong emphasis on sustainable development and could potentially contribute to environmental degradation. Therefore, it is essential to prioritize the long-term viability of investments through the strategic diversification of revenue streams. For Pakistan, through the execution of nonlinear autoregressive distributed lag (NARDL) for the period 1980–2018, Ahmad et al. (2022) revealed a positive linkage toward the injection of CO_2 in the ecosystem both in the long- and short-run assessment. The study established that the inflows of REM intensify the trend of CO_2 emissions, while the negative shock in REM supports ES both in the long and short run. A similar line of finding was obtained by Brown et al. (2020) for Jamaica, Karasoy (2021) for the Philippines, and Ahmad et al. (2019a) for China.

Rani et al. (2023) in SAARC economies documented that households receiving REM often experience lifestyle changes as they prioritize consumption and spend more money. This increase in income from REM can result in higher spending on energy-intensive goods and services, impacting the environment. In sub-Saharan Africa, without specific guidelines or policies, remittance money may not be used for environmentally friendly or sustainable investments. Instead, it could be invested in traditional sectors that could negatively impact the environment (Ali et al., 2022). Recipients of REM have the option to embrace modern technologies, which can have an impact on the environment. The ownership of electronic devices, vehicles, and other modern conveniences can lead to higher energy consumption and electronic waste (Shittu et al., 2021). In Bangladesh, enhancing the living standards by REM may lead to more investment in environmental education, which can help raise awareness and encourage sustainable practices (Sikder and Higgins, 2017). REM can fund conservation initiatives, like planting trees or preserving biodiversity, which promotes a more sustainable environment (Ruba and Talucder, 2023). People who receive REM can use the finances to start environmentally sustainable businesses, enabling green industries to grow (Mills, 2023). In GCC countries, REM can lead to changes in land use, like deforestation or the conversion of agricultural lands, which can impact the natural environment (Aloqab et al., 2023).

However, the association between REM and ES in Bangladesh also has negative aspects . Remittance-driven economic growth may lead to rapid urbanization and infrastructure development, harming the environment and destroying natural habitats (Serageldin, 2016). Without regulations to control industrial emissions and waste disposal, the economic growth driven by REM could lead to water and air pollution (Nandy, 2023). A group of researchers have confirmed the contributive role of REM in attaining the ED through CO_2 emission control. For instance, by taking the top eight REM recipient nations, Islam (2022), with the implementation of the PGM and DH causality test, revealed that the positive and negative shocks of REM foster the ED through the mitigation of CO_2 emissions both in the long and short run. Based on the literature, this study hypothesizes that

H1: There is a positive association between inflows of remittance and environmental degradation.

2.2 Export earnings and environmental sustainability

The impact of global trade on carbon emissions is a multifaceted issue, encompassing factors beyond the emissions produced during manufacturing and international transit (Wang et al., 2020; Gao et al., 2021). Trade plays a significant role in shaping the geographical distribution of output, which consequently impacts the level of emissions. The variability in emissions depends on the carbon intensity of production in different regions. Highlighting the significance of trade, it is crucial to note its pivotal role in spreading green technologies and facilitating the shift toward low-carbon economies (Derindag et al., 2023; Chhabra et al., 2023; Bagadeem et al., 2024). Nevertheless, Rahman et al. (2023) postulated that an increase in exports, coupled with significant economic benefits, could potentially result in a significant increase in carbon emissions, potentially impeding synchronized economics. A significant portion of global CO_2 emissions can be attributed to international trade. Significantly reducing these emissions is crucial to achieving climate change mitigation goals. The trade sector has the potential to greatly expedite the spread and adoption of clean technology and environmentally friendly goods and services. Export plays a crucial role in fostering innovation in clean technologies within the industrial sectors of developing nations (Galvan et al., 2022; Wu et al., 2021). Jiao et al. (2021) revealed that export offers the advantages of economies of scale, increased efficiency, and access to skills and information, thereby creating and strengthening incentives for innovation. In certain countries, exports have a varying impact on carbon dioxide emissions, with some nations experiencing a positive contribution while others observing a negative influence. Therefore, the influence of export revenues on CO_2 emissions is influenced by various factors, such as the carbon intensity of industries, technological advancements, and the nature of trade flows.

The correlation between export revenues and CO_2 emissions, along with its impact on environmental sustainability, is a multifaceted and intricate matter. Although the increase in export profits may lead to increased economic activity and energy consumption, potentially resulting in higher CO_2 emissions, it is important to recognize that export earnings can also contribute to the promotion of environmental sustainability (Zhou et al., 2022). Hassan et al. (2022) indicated that exporting can result in higher investments in pollution control measures and the implementation of more efficient manufacturing processes to address emissions. In addition, Shannak and Contestabile (2022) postulated that the increased market access enabled by free trade has the potential to lower production expenses for environmentally friendly products and offer cost advantages through economies of scale. In addition, research indicates that companies engaged in the export of goods tend to have reduced levels of pollution compared to non-exporting organizations. In addition, the process of trade liberalization may encourage exporters to allocate extra resources toward reducing pollution. Therefore, it is important to consider that the increase in CO_2 emissions is influenced by various factors despite its connection to export revenues. In addition, there are potential ways to ensure that the progress resulting from exports is in line with the objectives of ES (Wu et al., 2018).

Studies have shown that export revenues and investments made during the quality upgrading process can impact carbon dioxide emissions levels (Fang et al., 2019; Apergis et al., 2018). Furthermore, it has been found that certain economies are affected by carbon dioxide emissions resulting from exports. Research has indicated that the presence of export products can significantly influence the amount of CO_2 emissions in developed countries, both in the short and long run. Research has shown that the impact of carbon taxes on exports can be mitigated by reductions in payroll and other factors, effectively balancing out the higher production costs. Typically, international trade has a significant impact on CO_2 emissions. Efforts are constantly being made to assess the effects and analyze the potential benefits of regulating CO_2 emissions from shipping. Based on the existing literature, the study hypothesized that

H_2: There is a positive association between export earnings and environmental degradation.

2.3 Infrastructural development and environmental sustainability

The importance of infrastructural development for economic sustainability is well documented in the literature, particularly in relation to economic progress, industrial development (Worika and Umofia, 2017), the inflow of foreign direct investment (FDI), and improved living standards. Regarding environmental degradation, the impact of infrastructure development (IFD) has also been noted. The concept of sustainable infrastructure is crucial for long-term economic, social, and environmental benefits. Sustainable infrastructure involves the planning and implementation of various elements, such as roadways, buildings, energy systems, and water infrastructure, with a focus on considering the economic, social, and environmental impacts (Thacker et al., 2019). Achieving global climate objectives, Sustainable Development Goals, and a strong and resilient global economy are crucial. Sustainable infrastructure systems are known for their holistic approach to the entire life cycle, from planning and design to construction, operation, and decommissioning (Invernizzi et al., 2020). This approach ensures that the infrastructure remains sustainable in the long run, taking into account factors such as economic and financial viability, social impact, environmental considerations, and institutional support throughout its entire life cycle (Artmann et al., 2019). However, it is important to recognize that although sustainable infrastructure can offer economic, social, and environmental benefits, it demands a significant financial investment. To ensure the development of suitable infrastructure, policymakers need to create long-lasting strategies for sustainable national infrastructure systems, guided by the SDGs, and devise adaptable plans that can efficiently accomplish their goals (Qureshi, 2016). Therefore, it is of utmost importance to place a high priority on investing in sustainable infrastructure at this time, considering the simultaneous challenges posed by climate change, a global economic downturn, and the imperative to address inequalities that disproportionately affect the most vulnerable communities (Boyce, 2019).

In Bangladesh, strategic planning can result in investments in eco-friendly infrastructure, including sustainable transportation systems, urban development, and energy-efficient buildings (Abdullah-Al-Mahbub et al., 2022). Infrastructural development may involve implementing renewable energy projects, which can lower the dependence on non-renewable energy sources and reduce carbon emissions (Islam et al., 2022). Upgraded infrastructure can help create effective waste management systems, like recycling facilities and waste-to-energy technologies, which can reduce pollution (Roy et al., 2022). Thoughtfully designed infrastructure projects can also include restoring ecosystems, like reforestation programs and rehabilitating damaged landscapes (Ota et al., 2020). Infrastructure development can focus on creating sustainable transportation networks, such as public transit systems and bike lanes, to decrease the dependence on private vehicles and limit air pollution (Haque et al., 2020).

The negative aspects of the relationship between infrastructural development and ES in Bangladesh are also visible. Large infrastructure projects can cause land use changes and destroy habitats, harming biodiversity and disrupting local ecosystems (Rahman, 2015). If proper environmental assessments and measures are not taken, construction activities related to infrastructure development can lead to air and water pollution (Kabir and Khan, 2020). Certain types of infrastructure, especially those that use a lot of energy, can contribute to higher carbon emissions and environmental damage (Raihan et al., 2022). Infrastructure projects can result in deforestation for construction materials, negatively affecting natural habitats and ecosystems (Hasnat et al., 2018). Infrastructure development can disrupt water bodies in areas with abundant water and impact aquatic ecosystems and water quality (Sohel et al., 2015). Based on the existing literature, the following hypothesis was formulated:

H_3: Infrastructural development and environmental sustainability are adversely associated.

2.4 Technological innovation and environmental degradation

The emphasis on technical innovation in contemporary literature arises from its capacity to stimulate economic expansion and foster ecological sustainability (Song et al., 2019). Nabila et al. (2022) emphasized the significance of prioritizing TI to maximize the use of natural resources and stimulate economic expansion. TI enables nations to address the difficulties posed by limited resources resulting from population expansion while also maintaining environmental integrity. Furthermore, state-of-the-art environmental technologies have can stimulate economic expansion while simultaneously reducing CO_2 emissions (Balcilar et al., 2023; Sharif et al., 2023). Conversely, the development of financial inclusion may inadvertently bolster companies that contribute to pollution and excessively utilize energy, thus potentially resulting in adverse environmental implications. However, technological progress in the industrial sector, together with enhancements in reprocessing, adoption, and recycling techniques, may mitigate these negative consequences. Consequently, this fosters the conservation of the environment and enables advancements in the economy and society (de Vries and Ferrarini, 2017; Li and Qamruzzaman, 2023).

The significance of the effect of technological innovation on environmental footprints (EFs) is crucial although there is a dearth of thorough empirical information examining this impact. Although there have been studies examining the relationship between technology, innovation, and environmental quality, only a limited number of studies have considered the combined influence of innovation and research and development (R&D) on environmental quality. Furthermore, the bulk of research has mostly focused on carbon emissions as the main environmental measure (Awaworyi et al., 2019). Recent discoveries have shed light on the relationship between the progress of infrastructure, the development of environmentally friendly technologies, and their influence on material consumption. Razzaq et al. (2021) showed a significant association between the progress of infrastructure via the use of cutting-edge green technology and the material footprint. Ke et al. (2022) discovered in a recent study that progress in green technology innovation has the potential to greatly reduce environmental footprints in metropolitan regions. Furthermore, Ahmed Z. et al. (2022) and Liu et al. (2022) underscored the critical significance of technological innovation in reducing environmental footprints. Nabila et al. (2022) also demonstrated its substantial influence in mitigating environmental contamination.

In Bangladesh, renewable energy technologies like solar, wind, and hydroelectric power benefit the environment by reducing reliance on fossil fuels, decreasing greenhouse gas emissions, and combating climate change (Baky et al., 2017). Improvements in energy efficiency across different sectors, such as manufacturing, transportation, and buildings, positively impact the environment. By consuming less energy, carbon emissions are reduced, and natural resources are preserved (Reza et al., 2017). Advancements in precision agriculture, sensor-based farming, and data analytics lead to more sustainable and efficient farming practices. Smart farming optimizes resource usage, minimizes environmental harm, and improves productivity (Hossain and Islam, 2022). Innovations in waste management, including recycling processes and waste-to-energy systems, contribute to environmental sustainability. These technologies reduce the volume of waste sent to landfills, promote recycling, and generate cleaner energy from waste (Roy et al., 2022). These, in turn, reduce environmental degradation.

However, there are also some situations where TI indeed degrades the environment and hampers sustainability in Bangladesh. Extracting resources for specific innovations can lead to habitat destruction and deforestation. For instance, mining activities for rare earth metals and minerals used in technology can also harm soil and biodiversity (Siddique et al., 2020). Industrial innovations, such as manufacturing processes, can contribute to pollution if not managed sustainably (Raihan et al., 2022). Additionally, certain high-energy technologies like data centers and artificial intelligence can increase carbon emissions and have a significant environmental impact (Ahmed F. et al., 2022). It is important to note that recent research has shown inconsistent and inconclusive findings about the impact of technology improvements on environmental sustainability. Further investigation is required to obtain a thorough comprehension of the complex relationship between technological progress and its effects on the environment. This should include the consideration of a broader range of environmental indicators and the incorporation of numerous contextual elements. A summary of literature surveys is given in Table 1.

H4: Technological innovation (TI) fosters environmental sustainability

2.5 Gap in the existing literature

No study has yet explored the nexus between remittances, export earning, and ES in a single equation although very few studies have examined these factors in a scattered manner.

In a case such as Bangladesh, the potentials effects of REM and export earning on CO_2 and ecological footprint are yet to be extensively investigated.

2.6 Theoretical foundation of the study

The theoretical framework of the study "Unlocking environmental harmony through export earnings: exploring the impact of remittances and infrastructure growth" is based on several key economic and environmental theories. These theories provide a foundation for understanding the complex relationships between economic growth, environmental sustainability, and remittances in Bangladesh.

The study draws upon the EKC hypothesis, which posits that as an economy grows, environmental degradation increases up to a certain point, after which it begins to decrease (Yang et al., 2021; Yin and Qamruzzaman, 2024; Qamruzzaman, 2024; Wang et al., 2024). This framework can help analyze the relationship between export earnings and environmental impacts in different stages of economic development. The EKC hypothesis suggests that economic growth initially leads to environmental degradation, but as the income *per capita* increases, the environmental quality improves. This theory is crucial in understanding how Bangladesh's economic trajectory, influenced by remittances and exports, might follow this pattern. Remittances could be theorized to impact environmental outcomes through several pathways. According to the New Economics of Labor Migration (NELM), remittances can either alleviate financial constraints on environmental investments or, alternatively, increase consumption, thereby contributing to environmental degradation (Li et al., 2022a). The study could explore how remittances influence household capacity to invest in environmentally sustainable technologies or practices. Remittances have been identified as a vital source of foreign capital, which can have a significant positive influence on numerous economies, including foreign direct investment, technological innovation, and economic growth. However, remittance inflows have also been found to increase environmental degradation in some cases, particularly through their impact on energy utilization and industrial production. The theory of ecologically unequal exchange (EUE) can be used to analyze how infrastructure growth, facilitating industrialization, might lead to environmental degradation through the extraction and export of natural resources (Ahmad et al., 2019a). This theory helps in understanding the environmental costs transferred from developing to developed countries. The study could investigate how the growth of export-oriented industries in Bangladesh, facilitated by remittances and infrastructure development, affects environmental sustainability. The adoption of new technologies and innovation in these industries becomes crucial for reducing per-unit environmental impacts.

In summary, the theoretical framework of the study integrates various economic and environmental theories to provide a comprehensive understanding of the relationships between economic growth, environmental sustainability, and remittances in Bangladesh. The framework guides the analysis of how remittances and export earnings influence environmental outcomes and how infrastructure development and industrialization impact environmental sustainability.

TABLE 1 Summary of the literature survey.

Author	Nation (period)	Methodology	REM	ER	ID	TI
Bagadeem et al. (2024)	China (2011–2021)	Threshold regression approach		+		
Rani et al. (2023)	SAARC (1990–2020)	FMOLS, DOLS, and FE-OLS	–			
Raihan et al. (2023)	Thailand (1990–2020)	ARDL and DOLS		–		
Wang and Li (2023)	Global economies	49 academic studies		–		
Nandy (2023)	Bangladesh	Econometric models	–			
Hosan et al. (2023)	Emerging Asian countries (1985–2015)	CS-ARDL				–
Li and Yang (2023)	India, Bangladesh, Pakistan, and Sri Lanka (1988–2021)	AMG		–		
Ruba and Talucder (2023)	Bangladesh	Online electronic journal databases	+			
Aloqab et al. (2023)	GCC countries (2001–2019)	ARDL	–			
Galván et al. (2022)	South America	Optimization model		+		
Hassan et al. (2022)	China (1987–2019)	Markov-switching equilibrium correction model		+		
Shannak and Contestabile (2022)	Qatar (1970–2018)	FMOLS		+		
Islam et al. (2022)	Bangladesh (1990–2019)	Dynamic Autoregressie Distributed Lagged			+	
Roy et al. (2022)	Bangladesh	Econometric models				+
Hossain and Islam (2022)	Bangladesh (1961–2018)	Econometric models				+
Ali et al. (2022)	Sub-Saharan Africa (1996–2016)	GMM	–			
Abdullah-Al-Mahbub et al. (2022)	Bangladesh (2003–2022)	Econometric models			+	
Ahmad et al. (2022)	Pakistan (1980–2018)	ARDL and NARDL	+			
Ahmed et al. (2022a)	Bangladesh	Econometric models				–
Roy et al. (2022)	Bangladesh	Comprehensive method			+	
Raihan et al. (2022)	Bangladesh (1990–2019)	ARDL and DOLS			–	
Islam (2022)	BDG, CHN, NEG, and EGY	PGM and D-H causality	–			
Raihan et al. (2022)	Bangladesh	Econometric models				–
Shittu et al. (2021)	Bangladesh	Econometric models	–			
Wu et al. (2021)	Japan and China (2007–2015)			+		
Yang et al. (2021)	Brazil, India, China, and South Africa (1990–2016)	DSUR and D-H causality	+			–
Karasoy (2021)	Philippine	ARDL and NARDL	+			
Brown et al. (2020)	Jamaica	ARDL and NARDL	+			
Kabir and Khan (2020)	Bangladesh	EIA			–	
Siddique et al. (2020)	Bangladesh	Econometric models				–
Ota et al. (2020)	Bangladesh	Econometric models			+	
Ahmad et al. (2019a)	China	ARDL and NARDL	+			
Apergis et al. (2018)	19 developed (high-income) economies (1962–2010)	ARDL		–		
Hasnat et al. (2018)	Bangladesh	Econometric models			–	
Sikder and Higgins (2017)	Bangladesh	Qualitative study	+			
Reza et al. (2017)	Bangladesh	Econometric models				+

(Continued on following page)

TABLE 1 (*Continued*) Summary of the literature survey.

Author	Nation (period)	Methodology	REM	ER	ID	TI
Baky et al. (2017)	Bangladesh	Econometric models				+
Serageldin (2016)	Bangladesh	Econometric models	+			
Rahman (2015)	Bangladesh	Direct interviews, questionnaires, and side observation of concerned individuals			–	

TABLE 2 Measurements of variables and expected signs.

Variable	Notation	Definition	Expected sign
Environmental sustainability	CO_2	Carbon dioxide (CO_2) emissions *per capita*	
	EF	Ecological footprint per gha	
Remittances	REM	Total remittances received as a percentage of GDP	+
Export earnings	ER	Total export earnings as a percentage of the GDP Export diversification index	+/−
Infrastructural development	ID	Infrastructure investment as a percentage of GDP	+/−
Technological innovation	TI	Patent	–
Economic growth	Y	GDP per capital	+

3 Data and methodology of the study

3.1 Model specification

The relationship between remittances, export earnings, infrastructural development, and ES is complex and vital in Bangladesh. From 1980 to 2020, Bangladesh experienced significant changes in its economy, global connections, and environmental challenges. REM from the Bangladeshi diaspora and export earnings are crucial for the country's economy. Infrastructural development, particularly transportation and energy, is essential for economic growth. However, the sustainability of this growth is closely tied to environmental concerns as Bangladesh is vulnerable to climate change. This research aims to understand the connections between remittances, export earnings, infrastructural development, and ES to inform policy decisions and sustainable development in Bangladesh. This research proposes the following empirical model:

$$CO2_t \int REM_t, ER_t, IFD_t, \quad (1)$$

$$EF_t \int REM_t, ER_t, IFD_t. \quad (2)$$

To ensure the consistency and reliability of our results and facilitate interpretation, we transformed all variables in our study into their natural logarithmic forms, except for the TI and economic growth variables. This transformation is supported by previous research and allows us to capture the relationships among REM, export earnings (ER), infrastructural development (IFD), environmental sustainability (CO_2), TI, and economic growth (Y) in our empirical model. Additionally, referring to the existing literature, the study extended Equation 1, 2 with the EKC framework and added technological innovation as a control variable. The revised (Equation 3) is as follows:

$$CO2_t \int REM_t, ER_t, IFD_t, TI_t, Y_t, Y_t^2. \quad (3)$$

After the natural logarithm transformation, the above equation can be rewritten into the following regression (Equation 4):

$$CO2_t = \beta 0 + \beta 1REM_t + \beta 2EE_t + \beta 3IFD_t + \beta 4TI_t + \beta 5Y_t + \beta 6Y_t^2 + \varepsilon_t, \quad (4)$$

where CO_2 emissions are denoted by ($CO2_t$) and various independent variables include remittances (REM_t), export revenue (EE_t), infrastructural development (IFD_t), technological innovation (TI_t), income (Y_t), and income squared (Y_t^2). β0 represents the intercept, β1–β6 represent the coefficients of the respective independent variables, and ε_t represents the error term for details of the research varibables with proxy and data sources, see Tables 2, 3.

$$EF_t \int REM_t, ER_t, IFD_t, TI_t, Y_t, Y_t^2. \quad (5)$$

After the natural logarithm transformation, the above equation can be rewritten into the following regression equation:

$$EF_t = \beta 0 + \beta 1REM_t + \beta 2ER_t + \beta 3IFD_t + \beta 4TI_t + \beta 5Y_t + \beta 6Y_t^2 + \varepsilon_t, \quad (6)$$

where environmental sustainability is denoted by (EF_t) and various independent variables include remittances (REM_t), export revenue (ER_t), infrastructural development (IFD_t), technological innovation (TI_t), GDP (Y_t), and GDP squared (Y_t^2). β0 represents the intercept, β1–β6 represent the coefficients of the respective independent variables, and ε_t represents the error term.

3.2 Description of the data

The data used in this study cover the period from 1990 to 2020, encompassing significant economic and social changes globally and in Bangladesh spanning four decades. They highlight the increase in international migration and remittances, changes in trade policies and globalization, infrastructural development, ES concerns, policy changes and events, and long-term trends and patterns. The analysis aims to understand the impact of these factors on the economy and the environment in Bangladesh. For this study, we used the following data.

3.2.1 Remittances

The first explanatory variable, REM, is important for Bangladesh's economic development as many of its citizens work abroad, especially in the Middle East, and send money back home. This serves as a source of foreign exchange, helps alleviate poverty, and contributes to overall economic stability (Akter, 2016). Referring to the existing literature, the inflows of REM might adversely induce the ES through excessive conventional energy consumption and urbanization effects. Thus, it is anticipated that the sign of the REM coefficients in the empirical estimation is negative (-ve).

3.2.2 Export earnings

This is used as the second explanatory variable, which plays a crucial role in the economy of Bangladesh as it heavily relies on the exports of goods like garments, textiles, and agricultural products. These earnings contribute significantly to the country's GDP and foreign exchange reserves. Fluctuations in export earnings can indicate changes in global demand, trade policies, and the competitiveness of the country's exports (Islam, 2019).

3.2.3 Infrastructural development

This is used as an additional explanatory variable. Infrastructure development is crucial for economic growth and development in Bangladesh. It involves constructing roads, bridges, ports, and energy facilities. Enhancing infrastructure can boost productivity, connectivity, and the overall quality of life of the people (Rahman et al., 2014).

3.2.4 Environmental sustainability

This is the main dependent variable. In Bangladesh, ES is crucial due to the country's vulnerability to climate change and its potential effects on agriculture, water resources, and coastal areas. It is important to balance economic development with environmental conservation for the wellbeing of the population in the long run (Hoque et al., 2019).

3.2.5 Environmental Kuznets curve

The environmental Kuznets curve proposes that environmental degradation initially increases with economic development but eventually decreases as income levels increase and environmental regulations become more stringent (Dinda, 2004). The EKC framework can be used to analyze the relationship between economic development in Bangladesh and its impact on environmental sustainability.

3.3 Estimation strategies

We selected the model proposed by Pesaran et al. (2001) due to the following justifications: one primary rationale is that the integration orders of our series are distinct, denoted as I (0) and I (1). The error correction model enables the integration of short-term dynamics and long-term effects, which is the second reason.

$$\begin{aligned}\Delta lnCO_{2t} = \alpha_0 + \sum_{i=1}^{t}\beta_i \Delta lnCO_{2t-i} + \sum_{i=1}^{t}\rho_i \Delta lnREM_{t-i} + \sum_{i=1}^{t}\varphi_i \Delta lnEE_{t-i} \\ + \sum_{i=1}^{t}\omega_i \Delta lnIFD_t + \sum_{i=1}^{t}\Phi_i \Delta lnY_{t-i} + \sum_{i=1}^{t}\Phi_i \Delta lnY_{t-i}^2 \\ + \pi_1 lnREM_{t-i} + \pi_2 lnER_{t-1} + \pi_3 lnID_{t-1} + \pi_4 lnTI_{t-1} \\ + \pi_5 lnY_{t-1} + \pi_5 lnY_{t-1}^2 + \varepsilon_t,\end{aligned} \tag{7}$$

$$\begin{aligned}EF_{2t} = \alpha_0 + \sum_{i=1}^{t}\beta_i \Delta lnEF_{2t-i} + \sum_{i=1}^{t}\rho_i \Delta lnREM_{t-i} + \sum_{i=1}^{t}\varphi_i \Delta lnEE_{t-i} \\ + \sum_{i=1}^{t}\omega_i \Delta lnIFD_t + \sum_{i=1}^{t}\omega_i \Delta lnIFD_t + \sum_{i=1}^{t}\Phi_i \Delta lnY_{t-i} \\ + \sum_{i=1}^{t}\Phi_i \Delta lnY_{t-i}^2 + \pi_1 lnREM_{t-i} + \pi_2 lnER_{t-1} + \pi_3 lnID_{t-1} \\ + \pi_4 lnTI_{t-1} + \pi_5 lnY_{t-1} + \pi_6 lnY_{t-1}^2 + \varepsilon_t.\end{aligned} \tag{8}$$

The long-run relations in the empirical Eq () and () to be assessed with the execution of the following equation with a null of no-cointegration.

Pesaran et al. (2001) and Sam et al. (2019) each presented a unique set of asymptotic critical values in their respective research articles. The first set had regressors with an I (1) level, while the second set had regressors with an I (0) level. If there is no notable distinction between the absolute lower-bound critical value and the F-test statistic or *t*-test statistic, then it would not be possible to reject the null hypothesis of "no long-run connection." Both of these conditions must be met. Consequently, it became increasingly likely that the variables in the study were not connected. If the F-test statistic value or the *t*-test statistic absolute value exceeds the upper-bound critical value, it can be concluded that the null hypothesis is false. Whether the null hypothesis is rejected or not depends on both of these circumstances. We successfully fulfilled both of these criteria. There were clear connections between the variables over an extended duration, as demonstrated. Finally, if the value of the test statistic was neither lower nor higher than the two crucial values, suggesting that the value lay somewhere in the middle, then the conclusion about the long-run correlations between the variables was equivocal.

The short-term models are denoted by Equation 9 and Equation 10 below, where θi represents the long-run equilibrium adjustment speed after the short-run shock or error correction term.

$$\begin{aligned}\Delta ln\,CO_{2,t} = \beta_0 + \sum_{i=1}^{t}\beta_i \Delta ln\,REM_{t-i} + \sum_{i=1}^{t}\rho_i \Delta ln\,EE_{t-i} \\ + \sum_{i=1}^{t}\varphi_i \Delta ln\,IFD_{t-i} + \sum_{i=1}^{t}\omega_i \Delta ln\,TI_{t-i} + \sum_{i=1}^{t}\Phi_i \Delta Y_{t-i} \\ + \theta_i ECT_{t-i} + \varepsilon_t,\end{aligned} \tag{9}$$

$$\Delta ln\,EF_t = \beta_0 + \sum_{i=1}^{t}\beta_i\Delta ln\,REM_{t-i} + \sum_{i=1}^{t}\rho_i\Delta ln\,EE_{t-i} + \sum_{i=1}^{t}\varphi_i\Delta ln\,IFD_{t-i} + \sum_{i=1}^{t}\omega_i\Delta ln\,TI_{t-i} + \sum_{i=1}^{t}\Phi_i\Delta Y_{t-i} + \sum_{i=1}^{t}\Phi_i\Delta Y^2_{t-i} + \theta_i ECT_{t-i} + \varepsilon_t. \quad (10)$$

In the recent literature, the application of an asymmetric framework has been extensively used in effective policy formulation (Li and Qamruzzaman, 2022; Xia et al., 2022; Xu et al., 2021; Lingyan et al., 2021). The asymmetric framework assists in exploring the elasticity of explanatory variables through the decomposition of positive and negative shocks, which reveals fresh evidence over conventional relations. Nevertheless, it overlooks the asymmetric relationship that exists among the sub-study series. This further elucidates the rationale behind our decision to use the non-linear autoregressive distributed lag (ARDL) model in our research, which additionally obviates the need for sequential integration of all variables. Our methodology drew inspiration from that of Shin et al. (2014). Equation 2, as mentioned earlier, can be expressed as follows:

$$InCO2_t = \beta_0 + \beta_1 InREM_t^+ + \beta_2 InREM_t^- + \beta_3 InER_t^+ + \beta_4 InER_t^- + \beta_5 InID_t^+ + \beta_6 lnID_t^- + \beta_7 lnTI_t^+ + \beta_8 lnTI_t^- + \beta_8 lnY_t^+ + \beta_8 lnY_t^- + \varepsilon_t, \quad (11)$$

where $ln\,REM_t^+\ and\ ln\,REM_t^-$; $ln\,ER_t^+\ and\ ln\,ER_t^-$; and $ln\,IFD_t^+ and\ ln\,IFD_t^-$ are the decomposed variables of REM, IFD, and EE, respectively.

$$ln\,REM_t^+ = \sum_{j=1}^{t}\Delta\ln REM_j^+ = \sum_{j=1}^{t}\max(\Delta\ln REM_j, 0),$$

$$\ln REM_t^- = \sum_{j=1}^{t}\Delta\ln REM_j^- = \sum_{j=1}^{t}\min(\Delta\ln REM_j, 0),$$

$$ln\,EE_t^+ = \sum_{j=1}^{t}\Delta\ln EE_j^+ = \sum_{j=1}^{t}\max(\Delta\ln EE_j, 0),$$

$$\ln EE_t^- = \sum_{j=1}^{t}\Delta\ln EE_j^- = \sum_{j=1}^{t}\min(\Delta\ln EE_j, 0),$$

$$ln\,IFD_t^+ = \sum_{j=1}^{t}\Delta\ln IFD_j^+ = \sum_{j=1}^{t}\max(\Delta\ln IFD_j, 0),$$

$$\ln IFD_t^- = \sum_{j=1}^{t}\Delta\ln IFD_j^- = \sum_{j=1}^{t}\min(\Delta\ln IFD_j, 0).$$

By incorporating the above decomposed variables, the asymmetric equation can be displayed in the following manner:

$$\begin{aligned}\Delta\ln CO2_t = \beta_0 &+ \sum_{i=1}^{p}\beta_i\Delta\ln CO2_{t-i} + \sum_{i=1}^{p}(\beta_i^+\Delta\ln REM_{t-i}^+ + \beta_i^-\Delta\ln REM_{t-i}^-) \\ &+ \sum_{i=1}^{p}(\beta_i^+\Delta\ln EE_{t-i}^+ + \beta_i^-\Delta\ln EE_{t-i}^-) + \sum_{t-1}^{p}(\beta_i^+\Delta\ln IFD_{t-i}^+ + \beta_i^-\ln IFD_{t-i}^-) \\ &+ \sum_{i=1}^{p}(\beta_i\Delta TI_{t-i}) + \sum_{i=1}^{p}(\beta_i\Delta Y_{t-i}) + \sum_{i=1}^{p}(\beta_i\Delta Y_{t-i}^2) \\ &+ \lambda_1\,ln\,CO2_{t-i} + \lambda_2^+\,ln\,REM_{t-i}^+ + \lambda_3^-\,ln\,REM_{t-i}^- \\ &+ \lambda_4^+\,ln\,EE_{t-i}^+ + \lambda_5^-\,ln\,EE_{t-i}^- + \lambda_6^+\,ln\,IFD_{t-i}^+ + \lambda_7^-\,ln\,IFD_{t-i}^- \\ &+ \lambda_8 TI_{t-i} + \lambda_8 Y_{t-i} + \lambda_9 Y_{t-i}^2 + \varepsilon_t, \end{aligned} \quad (12)$$

$$\begin{aligned}\Delta\ln EF_t = \beta_0 &+ \sum_{i=1}^{p}\beta_i\Delta\ln EF_{t-i} + \sum_{i=1}^{p}(\beta_i^+\Delta\ln REM_{t-i}^+ + \beta_i^-\Delta\ln REM_{t-i}^-) \\ &+ \sum_{i=1}^{p}(\beta_i^+\Delta\ln EE_{t-i}^+ + \beta_i^-\Delta\ln EE_{t-i}^-) + \sum_{t-i}^{p}(\beta_i^+\Delta\ln IFD_{t-i}^+ + \beta_i^-\ln IFD_{t-i}^-) \\ &+ \sum_{i=1}^{p}(\beta_i\Delta TI_{t-i}) + \sum_{i=1}^{p}(\beta_i\Delta Y_{t-i}) + \sum_{i=1}^{p}(\beta_i\Delta Y_{t-i}^2) \\ &+ \lambda_1\,ln\,EF_{t-i} + \lambda_2^+\,ln\,REM_{t-i}^+ + \lambda_3^-\,ln\,REM_{t-i}^- \\ &+ \lambda_4^+\,ln\,EE_{t-i}^+ + \lambda_5^-\,ln\,EE_{t-i}^- + \lambda_6^+\,ln\,IFD_{t-i}^+ + \lambda_7^-\,ln\,IFD_{t-i}^- \\ &+ \lambda_8 TI_{t-i} + \lambda_8 Y_{t-i} + \lambda_9 Y_{t-i}^2 + \varepsilon_t. \end{aligned} \quad (13)$$

where $\sum_{i=1}^{p}\beta_{ii}^{+}$ and $\sum_{i=1}^{p}\beta_{ii}^{-}$ capture the positive and negative effects in the short term, respectively, whereas λ_i^+ and λ_i^- capture the positive and negative long-term effects, respectively. The error correction model in Equations 14, 15 is demonstrated as follows:

$$\begin{aligned}\Delta\ln CO2_t = \beta_0 &+ \sum_{i=1}^{p}\beta_i\Delta\ln CO2_{t-i} + \sum_{i=1}^{p}(\beta_i^+\Delta\ln REM_{t-i}^+ + \beta_i^-\Delta\ln REM_{t-i}^-) \\ &+ \sum_{i=1}^{p}(\beta_i^+\Delta\ln EE_{t-i}^+ + \beta_i^-\Delta\ln EE_{t-i}^-) + \sum_{t-i}^{p}(\beta_i^+\Delta\ln IFD_{t-i}^+ + \beta_i^-\ln IFD_{t-i}^-) + +\lambda_8 TI_{t-i} \\ &+ \lambda_8 Y_{t-i} + \lambda_9 Y_{t-i}^2 + \theta_i ECT_{t-i} + \varepsilon_t, \end{aligned} \quad (14)$$

$$\begin{aligned}\ln EF_t = \beta_0 &+ \sum_{i=1}^{p}\beta_i\Delta\ln EF_{t-i} + \sum_{i=1}^{p}(\beta_i^+\Delta\ln REM_{t-i}^+ + \beta_i^-\Delta\ln REM_{t-i}^-) \\ &+ \sum_{i=1}^{p}(\beta_i^+\Delta\ln EE_{t-i}^+ + \beta_i^-\Delta\ln EE_{t-i}^-) + \sum_{t-i}^{p}(\beta_i^+\Delta\ln IFD_{t-i}^+ + \beta_i^-\ln IFD_{t-i}^-) + +\lambda_8 TI_{t-i} + \lambda_8 Y_{t-i} \\ &+ \lambda_9 Y_{t-i}^2 + \theta_i ECT_{t-i} + \varepsilon_t. \end{aligned} \quad (15)$$

The standard Wald test is performed to examine the short-term symmetry β = β+ = β⁻ and long-term symmetry λ = λ+ = λ⁻ for remittance, export earnings, infrastructure development, TI, and economic growth. After confirming the long-run association, the dynamic multiplier effect is assessed, where a 1% change in $\ln REM_{t-i}^+, \ln REM_{t-i}^-$, $\ln ER_{t-i}^+, \ln ER_{t-i}^-$, $\ln ID_{t-i}^+, \ln ID_{t-i}^-$, $lnTI_{t-i}^+, lnTI_{t-i}^-$, and $\ln Y_{t-i}^+, \ln Y_{t-i}^-$ can be derived as follows:

$$k_h^+ = \sum_{j=0}^{p}\frac{\varnothing CO@_{t+j}}{\varnothing\ln REM_t^+}, k_h^+ = \sum_{j=0}^{p}\frac{\varnothing CO2_{t+j}}{\varnothing\ln REM_t^-}, h = 1, 2, 3, \quad (16)$$

$$k_h^+ = \sum_{j=0}^{p}\frac{\varnothing CO2_{t+j}}{\varnothing\ln EE_t^+}, k_h^+ = \sum_{j=0}^{p}\frac{\varnothing CO2_{t+j}}{\varnothing\ln EE_t^-}, h = 1, 2, 3, \quad (17)$$

$$k_h^+ = \sum_{j=0}^{p}\frac{\varnothing CO2_{t+j}}{\varnothing\ln IFD_t^+}, k_h^+ = \sum_{j=0}^{p}\frac{\varnothing CO2_{t+j}}{\varnothing\ln IFD_t^-}, h = 1, 2, 3. \quad (18)$$

Due to the distinct orders I (0) and I (1) in which our variables are integrated, the conventional Granger causality test is rendered ineffectual. The Granger causality test, as defined by Toda and Yamamoto (1995), is utilized in this instance. It is constructed upon a modified Wald (MWALD) test. According to Zapata and Rambaldi (1997), the MWALD test circumvents the challenges inherent in the conventional Granger causality test by disregarding the possibility of series non-stationarity or co-integration. By adapting a VAR model to the variable levels, Toda and Yamamoto (1995) mitigated the potential hazards linked to an erroneous determination of the series order of integration (Amiri and Ventelou (2012); Mavrotas and Kelly (2001). The See, Equations 19–24 for the proposed Granger causality test is as follows:

$$\begin{aligned} ln\,CO2_t = \alpha_0 &+ \sum_{i=1}^{k}\beta_{1i}\ln CO2_{t-i} + \sum_{j=k+1}^{D_{max}}\beta_{2j}\ln CO2_{t-j} \\ &+ \sum_{i=1}^{k}\lambda_{1i}\ln REM_{t-i} + \sum_{j=k+1}^{D_{max}}\lambda_{2j}\ln REM_{t-j} \\ &+ \sum_{i=1}^{k}\Phi_{1i}\ln ER_{t-i} + \sum_{j=k+1}^{max}\Phi_{2j}\ln ER_{t-j} \\ &+ \sum_{j=1}^{k}\varphi_{1i}\ln ID_{t-i} + \sum_{j=k+1}^{D_{max}}\varphi_{2j}\ln ID_{t-j} + \sum_{t=1}^{k}\rho_{1i}TI \\ &+ \sum_{j=k+1}^{D_{max}}\rho_{2j}TI_{t-j} + \sum_{j=1}^{k}\delta_{1i}Y + \sum_{j=k+1}^{D_{max}}\delta_{2j}Y_{t-j} + \varepsilon_{1t}, \end{aligned} \tag{19}$$

$$\begin{aligned} lnREM = \alpha_1 &+ \sum_{j=1}^{k}\beta_{1i}\ln CO2_{t-i} + \sum_{j=k+1}^{d_{max}}\beta_{2j}\ln CO2_{t-j} \\ &+ \sum_{i=1}^{k}\lambda_{1i}\ln REM_{t-i} + \sum_{j=k+1}^{d_{max}}\lambda_{2j}\ln REM_{t-j} \\ &+ \sum_{i=1}^{k}\Phi_{1i}\ln EE_{t-i} + \sum_{j=k+1}^{d_{max}}\Phi_{2j}\ln EE_{t-j} \\ &+ \sum_{i=1}^{k}\varphi_{1i}\ln ID_{t-i} + \sum_{j=k+1}^{d_{max}}\varphi_{2j}\ln ID_{t-j} + \sum_{i=1}^{k}\rho_{1i}TI_{t-i} \\ &+ \sum_{j=k+1}^{d_{max}}\rho_{2j}TI_{t-j} + \sum_{i=1}^{k}\delta_{1i}Y_{t-i} + \sum_{j=k+1}^{d_{max}}\delta_{2j}Y_{t-j}\,\varepsilon_{2t}, \end{aligned} \tag{20}$$

$$\begin{aligned} In\,EE_t = \alpha_3 &+ \sum_{i=1}^{k}\beta_{1i}\ln CO2_{t-i} + \sum_{j=k+1}^{d_{max}}\beta_{2j}\ln CO2_{t-j} \\ &+ \sum_{i=1}^{k}\lambda_{1i}\ln REM_{t-i} + \sum_{j=k+1}^{d_{max}}\lambda_{2j}\ln REM_{t-j} \\ &+ \sum_{i=1}^{k}\Phi_{1i}\ln EE_{t-i} + \sum_{j=k+1}^{d_{max}}\Phi_{2j}\ln EE_{t-j} \\ &+ \sum_{i=1}^{k}\varphi_{1i}\ln ID_{t-i} + \sum_{j=k+1}^{d_{max}}\varphi_{2j}\ln ID_{t-j} + \sum_{i=1}^{k}\rho_{1i}TI_{t-i} \\ &+ \sum_{j=k+1}^{d_{max}}\rho_{2j}TI + \sum_{i=1}^{k}\delta_{2j}Y_{t-i} + \sum_{j=k+1}^{d_{max}}\delta_{2j}Y + \varepsilon_{3t}, \end{aligned} \tag{21}$$

$$\begin{aligned} ln\,IFD_t = \alpha_4 &+ \sum_{i=1}^{k}\beta_{1i}\ln CO2_{t-i} + \sum_{j=k+1}^{d_{max}}\beta_{2j}\ln CO2_{t-j} \\ &+ \sum_{i=1}^{k}\lambda_{1i}\ln REM_{t-i} + \sum_{j=k+1}^{d_{max}}\lambda_{2j}\ln REM_{t-j} \\ &+ \sum_{i=1}^{k}\Phi_{1i}\ln EE_{t-i} + \sum_{j=k+1}^{d_{max}}\Phi_{2j}\ln EE_{t-j} \\ &+ \sum_{i=}^{k}\varphi_{1i}\ln IFD_{t-i} + \sum_{j=k+1}^{d_{max}}\varphi_{2j}\ln IFD_{t-j} + \sum_{i=1}^{k}\rho_{1i}TI_{t-i} \\ &+ \sum_{=k+1}^{d_{max}}\rho_{2j}TI_{t-j} + \sum_{i=1}^{k}\delta_{2j}Y_{t-i} + \sum_{j=k+1}^{d_{max}}\delta_{2j}Y + \varepsilon_{4t}, \end{aligned} \tag{22}$$

$$\begin{aligned} TI_t = \alpha_5 &+ \sum_{i=1}^{k}\beta_{1i}\ln CO2_{t-i} + \sum_{j=k+1}^{d_{max}}\beta_{2j}\ln CO2_{t-j} \\ &+ \sum_{i=1}^{k}\lambda_{1i}\ln REM_{t-i} + \sum_{j=k+1}^{d_{max}}\lambda_{2j}\ln REM_{t-j} \\ &+ \sum_{i=1}^{k}\Phi_{1i}\ln EE_{t-i} + \sum_{j=k+1}^{d_{max}}\Phi_{2j}\ln EE_{t-j} + \sum_{i=1}^{k}\varphi_{1i}\ln IFD_{t-i} \\ &+ \sum_{j=k+1}^{d_{max}}\varphi_{2j}\ln IFD_{t-j} + \sum_{i=1}^{k}\rho_{1i}TI_{t-i} + \sum_{j=k+1}^{d_{max}}\rho_{2j}TI_{t-j} \\ &+ \sum_{i=1}^{k}\delta_{2j}Y_{t-i} + \sum_{j=k+1}^{d_{max}}\delta_{2j}Y + \varepsilon_{5t}, \end{aligned} \tag{23}$$

$$\begin{aligned} Y_t = \alpha_5 &+ \sum_{i=1}^{k}\beta_{1i}\ln CO2_{t-i} + \sum_{j=k+1}^{d_{max}}\beta_{2j}\ln CO2_{t-j} + \sum_{i=1}^{k}\ln REM_{t-i} \\ &+ \sum_{j=k+1}^{d_{max}}\lambda_{2j}\ln REM_{t-j} + \sum_{i=1}^{k}\Phi_{1i}\ln EE_{t-i} \\ &+ \sum_{j=k+1}^{d_{max}}\Phi_{2j}\ln EE_{t-j} + \sum_{i=1}^{k}\varphi_{1i}\ln IFD_{t-i} \\ &+ \sum_{j=k+1}^{d_{max}}\varphi_{2j}\ln IFD_{t-j} + \sum_{i=1}^{k}\rho_{1i}TI_{t-i} + \sum_{j=k+1}^{d_{max}}\rho_{2j}TI_{t-j} \\ &+ \sum_{i=1}^{k}\delta_{2j}Y_{t-i} + \sum_{j=k+1}^{d_{max}}\delta_{2j}Y + \varepsilon_{5t}. \end{aligned} \tag{24}$$

4 Estimation and interpretation

4.1 Unit root tests

Table 4 displays the results of the variable integration order test through the application of the tests used by Perron and Vogelsang (1992) and (Ng and Perron, 2001) and the ADF test. Referring to the test statistics, the study unveiled the variables that are integrated in mixed order, that is, either at level I (0) or after the first difference, I (1), but none exposed in the second difference.

4.2 Co-integration test

Following the co-integration framework proposed by Bayer and Hanck (2013) and Maki (2012), the study investigated the long-term association between environmental sustainability, export earnings, remittances, infrastructural development, TI, and economic growth. Table 5 displays the results of the co-integration test. The test statistics of both co-integration tests are statistically significant at a 5% level, establishing a long-term association in the empirical nexus.

The study further investigated the co-integration test through the execution of symmetric and asymmetric frameworks and the test statistics derived from $F_{overall}$, t_{DV}, $and\ F_{IDV}$, shown in Table 6. The study exposed all the test statistics to become statistically significant at a 1% level, which is also valid for the EKC framework.

4.3 Long- and short-run coefficient estimation: linear and nonlinear framework

Table 7 displays the results of ARDL estimation with Panel A for long-run coefficients and Panel B for short-run coefficients. Referring to the coefficient, Y and Y_2 in both models found positive and negative signs toward environmental sustainability, confirming the presence of the EKC hypothesis that economic

TABLE 3 Null hypotheses for all three tests.

Co-integration test	Null hypothesis	Alternative hypothesis
F-bound test	$\pi_1 = \pi_2 = \pi_3 = \pi_4 = \pi_5 = \pi_6 = 0$	Any, $\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6 \neq 0$
t-test on the lagged dependent variable	$\pi_1 = 0$	$\pi_1 \neq 0$
F-test on the lagged independent variable	$\pi_2 = \pi_3 = \pi_4 = \pi_5 = \pi_6 = 0$	Any, $\pi_2, \pi_3, \pi_4, \pi_5, \pi_6 \neq 0$

TABLE 4 Results of unit root tests.

	Perron and Vogelsang test				ADF test	
	At level		First difference		At level	After first difference
Level	Test statistics	D-SB	Test statistics	D-SB	Test statistics	Test statistics
REC	−2.7339	2020	−7.1867	2015	−1.6639	−5.7288
EG	−2.4553	2010	−9.8114	2008	−2.0094	−4.4833
FDI	−1.7189	2000	−9.4719	1997	−1.2795	−8.5299
OP	−1.0421	1996	−10.0224	2004	−2.5487	−3.7475
	−2.8164	2018	−10.0815	2011	−0.5794	−3.6078
TR	−1.9526	2004	−8.4195	1995	−2.676	−3.7886

Panel B: Narayan unit root test				
	At level		After first difference	
	T-statistics	Time break	T-statistics	Time break
RE	−1.9973	2009:2003	−6.9767***	2009:2014
NREC	−2.0096	2006:2017	−7.0734***	2004:2018
FFC	−2.5379	2002:2013	−7.2037***	2003:2016
DCP	−2.6009	2006:2011	−8.6912***	2007:2000
BM	−3.3893	2004:2006	−7.1019***	2007:2004
DCF	−1.7788	1998:2015	−7.9317***	1998:2017

Panel C: Ng−Perron unit root test									
IQ	−2.3868	−1.4632	0.2302	8.2122		−19.5534	−3.756	0.1537	3.5742
DEBT	−2.2381	−0.8836	0.259	7.9229		−21.6782	−4.1367	0.1622	4.463
EPU	−2.0414	−1.4214	0.3191	7.3324		−22.8827	−5.6159	0.1737	4.7974
GS	−2.3595	−1.0421	0.2253	8.9082		−21.9029	−5.4008	0.1575	3.872
FD	−2.6254	−1.0519	0.2841	8.6726		−16.9886	−3.8153	0.1713	4.191
FDI	−1.9197	−0.9884	0.2422	7.9559		−24.8874	−4.0061	0.143	4.6075
				1%	−23.8	−3.42	0.143	4.03	
Asymptotic critical values: Ng and Perron (2001), Table 1				5%	−17.3	−2.91	0.168	5.48	
				10%	−14.2	−2.62	0.185	6.67	

growth initially accelerated CO_2 emissions and ecological degradation, but the positive effects on the environment have been documented after reaching a certain threshold level.

For REM, the coefficients in the long run (short run) exposed positive statistical significance at a 1% level, which is found in both models. Notably, a 10% change in REM will result in the augmentation of CO_2 emissions in the long run (short run) by 1.531% (0.178%) and ecological degradation by 0.725% (0.187%). The study findings showed that an increase in the amount of money sent back to Bangladesh by its residents could potentially result in a more significant amount of CO_2 emissions and ecological degradation. This is consistent with the findings of other research, such as those by Yang et al. (2021); Ahmad et al. (2019a); and Li et al. (2022a). Remittance inflows can have a negative impact on the environment if they are used to support industries and products that have a significant carbon footprint, like automobiles and air conditioners. Households may increase their energy consumption and CO_2 emissions by purchasing high-energy-consuming items using remittances (Peever and Fuller, 2016). Investing in clean energy and environmentally friendly technologies can help alleviate the adverse impact of REM on the environment (Rahman et al., 2023). Additionally, the coefficients of REM square revealed negative and statistically significant results at 1% for both models, suggesting a U-invert association between REM inflows and environmental degradation. The study findings repostulate that after a certain point in time, the inflows of REM

TABLE 5 Results of the Bayer–Hanck and Maki co-integration tests.

Panel A: Bayer–Hanck combined co-integration without a structural break		
Test	Statistics	
EG-JOH	14.984	22.87
EG-JOH-BO-BDM	37.718	47.807
Panel B: Maki co-integration with a structural break		
	Test statistics [break year]	Test statistics [break year]
Level shift with trend	−7.0149 [1996:1999:2019]	−9.1779 [1996:2000:2011]
Regime shifts	−9.8628 [2003:2001:2012]	−12.3946 [2005:2010:2009]
Regime shifts with trend	−11.0868 [1993:2010:2009]	−18.4914 [1996:2004:2007]

TABLE 6 Bound co-integration test: linear and nonlinear frameworks.

		Symmetric framework			Asymmetric framework		
		$F_{overall}$	t_{DV}	F_{IDV}	$F_{overall}$	t_{DV}	F_{IDV}
$CO2_t \int REM_t, ER_t, IFD_t, TI_t, Y_t$	1	10.909***	−6.103***	8.165***	13.332***	−5.44***	10.727***
$CO2_t \int REM_t, ER_t, IFD_t, TI_t, Y_t, Y_t^2$	2	14.607***	−6.474***	8.211***	13.128***	−6.267***	7.905***
$EF_t \int REM_t, ER_t, IFD_t, TI_t, Y_t$	3	9.294***	−6.544***	6.331***	11.988***	−6.486***	8.532***
$EF_t \int REM_t, ER_t, IFD_t, TI_t, Y_t, Y_t^2$	4	7.546***	−5.694***	11.12***	15.309***	−6.497***	8.954***

will become critical factors in the process of environmental sustainability. Our findings are supported by those obtained by Dilanchiev et al. (2024); Qamruzzaman (2023a); and Qamruzzaman (2023d).

The coefficients of TI in the long run (short run) toward CO_2 emissions and ecological footprint are negative and statistically significant at a 1% level, postulating that positive changes in TI will result in support for achieving ES by the control of CO_2 emissions and ecological stability. Precisely, a 1% further progress in TI could lead to a reduction in CO_2 emissions in the long run (short run) by 0.1724% (0.083%) and ecological improvement by 0.1407% (0.0722%). Our study is supported by the studies of Yang et al. (2021) and (Hosan et al. 2023).

The study documented an adverse linkage between the adverse connection between export earnings and environmental sustainably both in the long- and short-run assessment, which is available in both model estimations. Referring to long-run coefficients, a 10% change in EEs will result in a 0.913% change in CO_2 emissions and a 1.229% change in ecological degradation, while for the short run, CO_2 emissions increase by 0.631% and ecological instability increases by 0.629%. Our study findings are in line with empirical studies by Li et al. (2021); Numan et al. (2023); and Manga et al. (2023). The coefficients of EE-squared were found to be negative and statistically significant at 1%, confirming an inverted U-shaped connection toward environmental degradation. The study findings advocated that after a certain point in time, the earnings from exports will boost the process of environmental sustainability. The findings are supported by those obtained by Malec et al. (2023). Investment in infrastructural development has caused detrimental effects on environmental development in both model estimations, indicating that construction work for infrastructural development degraded the present state of environmental quality in the long- and short-run assessment. Notably, a 10% increase in IFD may result in ED with a 1.229% increase in CO_2 emissions and a 0.533% increase in the ecological footprint by in the long run, while in the short run, CO_2 emissions increase by 0.249% and the ecological footprint increases by 0.719%.

The results of residual diagnostic test following $B–G_{LM\,TEST}$; $ARCH_{TEST}$; $BPG_{TEST} RRESET_{TEST}$; and $J-B_{TEST}$ and the test statistics of each estimation revealed no serial correlation, the absence of heteroscedasticity residuals are typically distributed and mode construction efficiency and consistency.

4.4 Nonlinear estimation: asymmetric coefficients of REM, EE, and IFD

The long- and short-run asymmetric coefficients of REM, EE, and IFD are given in Table 8, with Panel A for long-run coefficients and Panel B for short-run coefficients.

The study exposed the asymmetric coefficients of REM, i.e., REM^+ and REM^-, and found them to be positive and statistically significant toward CO_2 and EF in both the long and short run. The study findings suggest that a 1% positive (negative) change in EM will result in the amplification (contraction) of ED with the channel of excessive CO_2 emission by 0.1438% (*0.0418%*) and ecological footprint by 0.1815% (*0.1083%).* Additionally, in the

TABLE 7 Results of ARDL estimation.

	[1]			[2]		
	Coefficient	T-stat	Standard error	Coefficient	T-stat	Standard error
Panel A: long-run coefficients						
Y	0.0615	0.0037	16.6216	0.1348	0.0073	18.4657
Y^2	−0.1248	0.0051	−24.4705	−0.0394	0.0034	−11.5882
REM	0.1531	0.0107	14.3084	0.0725	0.0088	8.2386
REM^2	−0.0768	0.0047	16.3404	−0.0535	0.0078	6.8589
EE	0.0913	0.0095	9.6105	0.1229	0.0064	19.2031
EE^2	−0.0565	0.0029	19.4827]	−0.0675	0.0022	30.6818
IFD	0.1229	0.0087	14.1264	0.0533	0.0041	13.0211
TI	−0.1724	0.0023	−74.9565	−0.1407	0.0049	−28.7142
c	−0.1283	0.01015	−12.6419	0.04038	0.0103	3.9109
Panel B: short-run coefficients						
Y	0.0641	0.0058	11.0517	0.0518	0.0114	4.5438
Y^2	−0.0223	0.008	−2.7875	−0.0322	0.0098	−3.2857
REM	0.0178	0.0117	1.5213	0.0187	0.0105	1.2467
EE	0.0631	0.0055	11.4545	0.0629	0.0041	15.3414
IFD	0.0249	0.0074	3.3648	0.0719	0.0018	39.9444
TI	−0.083	0.0541	−1.537	−0.0722	0.0119	−6.0672
ECT	−0.7581	0.0176	−42.9241	−0.2563	0.01561	−16.4197
Panel C: diagnostic test						
EKC	YES			YES		
$B\text{–}G_{LM\,TEST}$	0.7643			0.8236		
BPG_{TEST}	0.6769			0.7917		
$ARCH_{TEST}$	0.7914			0.7151		
$RRESET_{TEST}$	0.8485			0.7596		
$J-B_{TEST}$	0.7306			0.7232		

short run, asymmetric coefficients of REM displayed contributory effects on ED. That is, a 1% positive (negative) shock in REM will support ES (degradation), indicating that the short-run money supply in the economy fosters clean consumption among the residents (Li and Qamruzzaman, 2023; Md Qamruzzaman and Anandha, 2021).

For expert earning, the asymmetric coefficients of EEs were unveiled to be positive and statistically significant at a 1% level both in the long- and short-run assessment. Notably, a 10% increase (decrease) in EEs will result in the acceleration (reduction) of CO_2 emissions by 1.204% (0.814%) and ecological footprint by 0.768% (0.178%). In the short run, CO_2 emissions increased by 0.0367% (0.0365%) and ecological footprint by 0.018% (0.0091%). The asymmetric effects of EEs are more significant in the long run than those of short-run coefficients. Thus, it is suggested that policy formulation in progressing EEs has to target long-run strategic goals.

Asymmetric investment in IFD, that is, positive (negative) changes, is positive and statistically significant at a 1% level, indicating that environmental adversity is the outcome of infrastructural development both in the long run ($CO2-IFD^{+}_{0.1511}$: $EF-IFD^{+}_{0.0769}$: $IFD^{+}_{0.1071}$: $IFD^{+}_{0.0763}$) and short run ($CO2\text{–}IFD^{-}_{0.0344}$: $EF-IFD^{+}_{0.0637}$), which is valid in both model estimations with CO_2 and EF. In particular, a 1% increase (decrease) in IFD in the long run will exacerbate the ED through excessive CO_2 by 1.511% (0.769%) and ecological footprint by 1.071% (0.763%). The study findings advocate that the cost of ED should be borne in mind while initiating further investment in infrastructural development both in the long and short run.

The symmetry test results given in Panel C show that the test statistics derived with a standard Wald test are statistically

TABLE 8 Results of asymmetric estimation.

	CO_2			EF		
Panel A: long-run coefficients						
REM^+	*0.1438*	*0.0116*	*12.3065*	*0.1815*	*0.0087*	*20.8286*
REM^-	*0.0418*	*0.0095*	*4.3686*	*0.1083*	*0.0112*	*9.6598*
EE^+	*0.1204*	*0.0094*	*12.7151*	*0.0768*	*0.0043*	*17.8505*
EE^-	*0.0814*	*0.0036*	*22.0430*	*0.0178*	*0.0103*	*1.7149*
IFD^+	0.1511	0.0053	28.1748	0.1071	0.0118	9.0354
IFD^-	0.0769	0.0096	7.9794	0.0763	0.0091	8.3267
REM^+	0.0937	0.0095	9.8120	0.0659	0.0070	9.3074
Y	0. 4728	0.0503	9.3901	0.2491	0.0216	11.5311
Y_2	−0.3472	0.0022	−138.657	−0.22414	0.0099	−22.4248
Panel B: short-run coefficients						
REM^+	−0.0469	0.0022	−21.3181	−0.0356	0.0028	−12.7142
REM^-	−0.0402	0.0048	−8.375	−0.0381	0.0113	−3.3628
EE^+	0.0367	0.0058	6.3275	0.018	0.0077	2.3376
EE^-	0.0365	0.0031	11.7741	0.0091	0.0082	1.1097
IFD^+	0.0086	0.0113	0.761	0.0637	0.0055	11.5818
IFD^-	0.0344	0.0066	5.2121	0.007	0.0061	1.1475
Y	0.0631	0.0094	6.7127	0.0098	0.0062	1.5806
Y2	−0.0576	0.0075	−7.68	−0.0614	0.0104	−5.9038
Panel –C: Long-run and short-run symmetry test						
REM_{LR}	7.995			5.597		
REM_{SR}	2.801			7.433		
EE_{LR}	7.933			4.583		
EE_{SR}	5.929			5.749		
IFD_{LR}	3.444			4.268		
IFD_{SR}	9.593			2.862		

TABLE 9 Results of the residual diagnostic test.

Test	*p*-value	Remarks	*p*-value	Remarks
$B\text{–}G_{LM\,TEST}$	0.726	Null-rejected	0.575	Null-rejected
BPG_{TEST}	0.52	Null-rejected	0.782	Null-rejected
$ARCH_{TEST}$	0.559	Null-rejected	0.671	Null-rejected
$RRESET_{TEST}$	0.877	Efficient estimation	0.671	Efficient estimation
$J-B_{TEST}$	0.677	Normal distribution	0.739	Normal distribution

significant at a 1% level, rejecting the null hypothesis of symmetric association both in the long and short run. Alternatively, a symmetric association has been revealed both in the long and short run.

The residual diagnostic results (see Table 9) confirmed that both models are free from serial correlation on heteroscedasticity, and residuals are normally distributed. Thus, it assumes empirical model construction consistency and estimation efficiency.

TABLE 10 Results of TY causality with a linear framework.

	Explanatory variables						Decision
Dependent variable	CO_2	REM	EE	IFD	TI	Y	CO_2←→REM; CO_2←→EE; CO_2←→TI; IFD→ CO_2; CO_2→Y; REM←→Y; EE→REM; IDF→REM; EE←→TI; Y→EE; IDF→Y; TI←→Y
CO_2		11.748***	6.888**	5.688*	5.981*	0.662	
REM	4.537*		5.112*	5.33*	1.153	6.552**	
EE	6.586**	3.124		1.96	7.166**	4.694*	
IFD	0.362	3.221	2.418		1.302	1.89	
TI	4.579*	3.57	4.51*	1.323		6.321**	
Y	6.889**	4.252*	1.379	4.185*	5.64*		
EF		4.628*	4.017*	1.809	6.677**	11.572	REM←→EF; EF←→TI; EE→EF; Y→EF EF→IFD; REM←→IFG; Y→REM; IFD→EE; EE←→TI; Y→TI
REM	5.534*		4.824*	6.387**	1.652	6.289**	
EE	1.372	3.62		6.66**	6.188**	0.868	
IFD	6.704**	6.176**	2.788		1.825	0.993	
TI	7.122**	0.833	5.061*	3.777		4.607*	
Y	2.721	1.422	4.993*	4.443*	2.795		

The superscripts ***/**/* denote the level of significant at 1%, 5%, and 10%, respectively.

4.5 T-Y causality test: symmetric and asymmetric framework

For documenting the directional association in the empirical relations, the present study implemented the causality test following Toda and Yamamoto (1995), and the results are given in Table 10. Referring to the symmetric framework causality test, the study disclosed the feedback hypothesis in explaining the causal association between ED, remittances, export earnings, and technological innovation [ED←→REM; ED←→EE; ED←→TI]. Additionally, the unidirectional association between Y→ED and IFD to ED.

Referring to results (see Table 11) of the causality test with the asymmetric framework, a study revealed that the feedback hypothesis holds in explaining the causal effects running between positive shocks in REM, EE, IFD, and CO_2 for ecological footprint, bidirectional linkage available for positive and negative shocks in REM, and positive shocks in EE. Furthermore, a unidirectional association was exposed between CO_2, adverse shocks in EE, and IFD see, Figure 1.

5 Discussion and policy implications of the study findings

The study documented the coefficients derived with symmetric and asymmetric estimation and found positive and statistical significance at a 1% level, both in the long and short run. Our study exposed the detrimental effects of REM in achieving ES in Bangladesh; mainly, the increase in remittance receipts by the residents will result in the acceleration of excessive CO_2 emissions and ecological degradation. Our study findings are in line with those obtained by Dash et al. (2024); Li et al. (2022b); Islam (2022); Ahmad et al. (2022); Karasoy (2021); and Ahmad et al. (2019a). The study findings indicate that REM in Bangladesh could potentially have negative impacts on environmental sustainability, specifically by contributing to increased CO_2 emissions and ecological degradation. Dash et al. (2024), using the ARDL model, indicated that REM have a detrimental effect on CO_2 emissions in Bangladesh and other countries such as Sri Lanka, Pakistan, and the Philippines. A recent study conducted by Bangladesh Bank has highlighted the allocation of a substantial portion of REM toward sectors such as real estate, small and medium companies, and financial investment. However, its usage can have adverse effects on the environment (Szabo et al., 2022). In addition, Ahmad et al. (2019a), Haque et al. (2022), and Liu et al. (2021) indicated that REM have a positive impact on the likelihood of rural families in Bangladesh adopting greener energy sources for cooking. Therefore, the available data indicate that while REM are vital for the economy, they may also pose challenges to ES in Bangladesh. The study findings align with those of previous research, suggesting that REM are frequently not used for sustainable development and could potentially contribute to environmental degradation. The positive impact of REM on poverty reduction and family expenses is accompanied by an increased demand for energy and fuel, potentially resulting in a decrease in environmental quality (Zhao and Qamruzzaman, 2022). The study findings underscored the importance of adopting a holistic approach when utilizing REM in Bangladesh. It is crucial to ensure that these funds are utilized to promote economic advancement while also safeguarding the environment. Policymakers and stakeholders should prioritize the implementation of mechanisms that encourage the allocation of REM toward sustainable development projects and clean energy solutions. This will help reduce the negative environmental impact often associated with remittance inflows.

Research on the EKC hypothesis, as well as the impact of remittances, export earnings, and infrastructure development on

TABLE 11 Results of TY causality: asymmetric framework.

	ED	REM$^+$	REM$^-$	EE$^+$	EE$^-$	IFD$^+$	IFD$^-$	TI	Y
Panel A: ED measures by CO_2 emissions									
ED	—	7.1828***	2.154	4.8252*	3.0324	7.8297***	3.0329	1.9117	3.3315
REM$^+$	5.5222**	—	5.5468**	0.8495	1.9391	1.3353	0.5244	6.0673***	4.02*
REM$^-$	4.2631*	6.9044***	—	1.166	0.9206	2.2464	1.5858	3.3956	4.8953*
EE$^+$	6.3151***	2.5126	2.3868	—	7.0172***	4.6165*	1.8637	5.8492**	4.8414*
EE$^-$	7.646***	1.1601	1.8198	2.0953	—	2.7014	4.3086*	3.9893*	2.939
IFD$^+$	5.1785**	6.8489***	6.4352***	6.9627***	6.6495***	—	7.7055***	3.3634	5.2825**
IFD$^-$	3.5726*	3.9878*	7.633***	4.6918*	3.8053*	4.8387*	—	3.9797*	4.0094*
TI	4.0093*	6.8026***	5.2306**	4.0922*	3.9334*	0.4177	5.1842**	—	7.1432***
Y$^-$	0.7028	0.0827	5.2362**	0.3352	2.3653	4.7495*	5.8318**	3.1045	—
Panel B: ED measures by ecological footprint									
ED	—	7.8674***	5.3557**	0.2012	6.1505***	0.5826	1.735	5.2402**	7.1928***
REM$^+$	5.9385**	—	3.5159*	3.711*	2.7658	4.113*	0.515	2.8465	4.5467*
REM$^-$	5.4789**	5.8135**	—	6.8484***	3.8925*	1.171	6.6207***	3.4448	4.1204*
EE$^+$	2.5594	3.2874	7.1313***	—	6.6294***	4.949*	5.7975**	3.5247*	0.727
EE$^-$	7.4717***	7.5722***	5.0082**	4.0796*	—	3.793*	2.24	3.4698	0.4443
IFD$^+$	7.7585***	6.7341***	5.15**	6.4497***	6.746***	—	0.6931	5.9506**	1.0017
IFD$^-$	0.1019	5.4843**	7.3711***	4.8745*	3.756*	1.0509	—	6.5996***	7.0608***
TI	1.661	4.4907*	3.3617	5.1389**	1.6162	6.4653***	0.0473	—	1.5972
Y	6.1767***	0.3034	4.8515*	1.935	1.5058	2.1935	7.0994***	6.0817***	—

The superscripts ***/**/* denote the level of significant at 1%, 5%, and 10%, respectively.

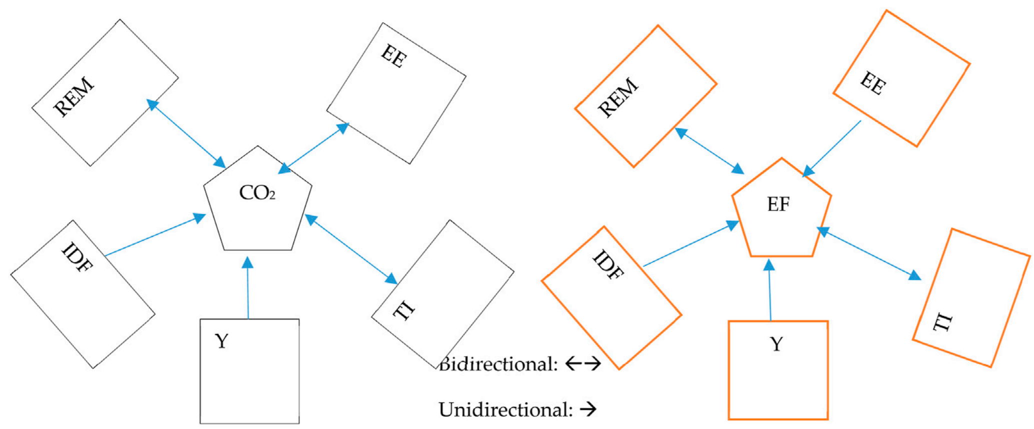

FIGURE 1
Directional causality.

environmental sustainability, is a highly intriguing field of study. The EKC hypothesis suggests that environmental degradation tends to increase with economic growth but then decreases once a certain level of income is attained. There appears to be a complex connection between economic development and environmental quality. However, to fully grasp the intricate ways in which remittances, export earnings, and infrastructure development affect the environment, a more detailed analysis is necessary.

Remittances, for instance, are financial transfers sent by migrants to their home countries, which often make a substantial contribution to household incomes. Remittances have the potential to contribute to an increase in the consumption of goods and services, potentially leading to an increase in carbon emissions and ecological degradation. The impact is driven by shifts in consumption patterns, with an increase in the usage of vehicles, household appliances, and other energy-intensive goods. In addition, remittances have the potential to impact land use patterns. For example, families may choose to invest in agricultural expansion or construction projects, which can result in deforestation and the destruction of habitats.

Export earnings and infrastructure development are key factors that significantly influence environmental outcomes. Intensified industrial activities and agricultural practices, driven by the pursuit of higher export earnings, can put a strain on natural resources and contribute to pollution. For example, the growth of industries to meet export demands could lead to higher levels of greenhouse gas emissions and water contamination caused by industrial waste. Infrastructure development is crucial for driving economic growth, but it can also have both positive and negative impacts on the environment. Improved infrastructure has the potential to greatly enhance efficiency and minimize environmental impact by implementing advanced transportation systems and adopting cleaner technologies. However, it is important to consider the potential ecological consequences of large-scale infrastructure projects, such as roads, bridges, and urban development. These projects can result in significant disruptions to the environment, including the loss of biodiversity and an increase in carbon emissions during the construction phases.

The research findings suggest a correlation between export revenues, carbon emissions, and ecological footprint, which remains consistent in both the long and short term and is relevant to both linear and nonlinear estimation methods. Our study findings are supported by those obtained by Wang K. et al. (2023), Çatık et al. (2024), and Huang et al. (2023). Hao (2022) and Dogan et al. (2020) postulated that export revenues contribute to environmental degradation as they encourage increased production and industrial activities, leading to greater energy consumption and resource utilization, which results in an increase in carbon emissions and ecological footprints. Furthermore, Huang and Wu (2022) revealed that expansion frequently relies on accelerated resource extraction, leading to the destruction of forests, harm to habitats, and the exhaustion of resources. Zhang et al. (2023) assessed the link between industrial production and exports contributing to the pollution of the air, water, and soil, resulting in negative impacts on ecosystems, biodiversity, and human health. Furthermore, the transportation of exported goods over long distances contributes to the release of greenhouse gases, which worsens environmental harm. Furthermore, the pursuit of export-led development often leads to a disregard for environmental sustainability as businesses can operate without strict environmental regulations or enforcement, exacerbating the negative impact on the environment (Ju et al., 2023; Hao, 2022; Wang Y. et al., 2023; Qamruzzaman, 2023b; Qamruzzaman, 2023c). In addition, the enforcement of stringent environmental regulations in importing countries could result in a phenomenon called "carbon leakage," where businesses relocate their operations to regions with less stringent requirements, which ultimately leads to an increase in carbon emissions and ecological footprints in the countries that export these goods (Williams et al., 2022; Ullah et al., 2023; Su et al., 2023). Our findings highlight the importance of implementing policy measures that specifically address carbon emissions and ecological footprint to effectively mitigate environmental degradation, which may involve implementing environmental regulations that specifically target carbon-intensive industries and promote the adoption of sustainable practices. In addition, research underscores the importance of incorporating both linear and nonlinear estimates in policy formulation, emphasizing the need for comprehensive and adaptable strategies to address environmental issues. The study results further reinforce the importance of prioritizing institutional quality, economic reforms, and political reforms in order to address environmental degradation effectively. The study findings are consistent with those of previous research, highlighting how REM can influence environmental degradation by impacting carbon emissions and ecological footprint see, for instance, [Hao (2022); Chunyu et al. (2021); and Dogan et al. (2020]. Therefore, it is crucial for policymaking and decision-making processes to consider the impact of REM on carbon emissions and ecological footprint. Moreover, it is essential to establish effective methods that ensure that REM play a significant role in promoting sustainable development.

The study findings suggest a clear link between the allocation of resources toward infrastructure development and the subsequent impact on carbon emissions and ecological footprint. The results are consistent in both the short and long term and are applicable to estimating methods that are both linear and nonlinear. As a result, the development of infrastructure in Bangladesh could lead to increased environmental degradation, which would require additional funding for environmental conservation. The hypothesis posits that the augmentation of infrastructure in Bangladesh would result in escalated environmental protection expenditures. Our study is in line with other studies (Awad et al., 2023; Balsalobre-Lorente et al., 2023; Liu et al., 2023). According to the findings, it appears that the development of infrastructure has negative impacts on the environment and that this IFD places a substantial strain on energy and resources, resulting in increased greenhouse gas emissions and ecological damage. Wang et al. (2022) suggested that the majority of greenhouse gas emissions, approximately 79%, come from infrastructure. Additionally, a significant portion, approximately 88%, of the expenses related to adapting to climate change is also attributed to infrastructure. Thus, it is an essential area that demands urgent focus when it comes to taking action on climate change. Luo et al. (2018) and Giang and Sui (2011) advocated that the development of infrastructure frequently results in the loss of habitats, fragmentation of ecosystems, and depletion of resources. Young (2023) and Das and Dutta (2023) unveiled that deforestation, habitat damage, and resource exhaustion are expected outcomes. The transportation of exported commodities over long distances contributes to the release of greenhouse gases, exacerbating environmental harm (Qin et al., 2020). Chen et al. (2020) and Jugurnath et al. (2017) established that the disregard for ES due to the focus on export-driven economic growth, which can lead to companies operating without strict environmental standards or enforcement, in turn, exacerbates the negative impact on the environment. Therefore, the findings of the study highlight the importance of taking comprehensive measures to address the environmental impacts of infrastructure development. This includes embracing sustainable production techniques, enforcing stringent environmental regulations, and promoting global cooperation to mitigate the negative consequences of increased investment in infrastructure.

6 Policy implications based on study findings

The findings highlight the significance of implementing policy measures that effectively address carbon emissions and ecological footprint to combat environmental degradation, which could involve the implementation of environmental policies that prioritize the reduction in carbon emissions from industries and promote the adoption of sustainable practices. Furthermore, this study emphasizes the importance of considering both linear and nonlinear estimations when developing policies. It highlights the importance of adopting comprehensive and adaptable strategies to address environmental issues. Furthermore, previous studies suggest that the adoption of economic and political reforms plays a crucial role in safeguarding the environment. The impact of institutions on reducing environmental degradation is widely recognized. Therefore, the study findings emphasize the importance of prioritizing institutional quality, economic reforms, and political reforms in order to address environmental degradation in policymaking and decision-making effectively. In relation to the effect of REM on environmental degradation, the findings of the study are consistent with those of previous research that highlights the role of REM in increasing carbon emissions and ecological footprint. Policymakers and decision-makers should consider the impact of REM on carbon emissions and ecological footprint. It is essential to implement measures that guarantee that REM are utilized to promote sustainable environmental practices. In general, the study findings emphasize the significance of implementing comprehensive environmental policies that consider factors like carbon emissions, ecological footprint, institutional quality, and the potential impact of REM on environmental degradation. It is essential to make informed decisions and implement policies that promote sustainable environmental practices and minimize the adverse effects of carbon emissions and ecological footprint on the environment.

Based on the search results, it appears that there is a lack of specific information regarding the policy implications of the study findings for the government and private sector of Bangladesh. However, the literature offers some broad policy implications. It would be advantageous for the government to embrace policies that promote sustainable development, such as investing in renewable energy and encouraging energy-efficient practices. The government could consider implementing more stringent environmental regulations to promote environmentally sustainable infrastructure development. It would be advantageous for the private sector to consider adopting sustainable production practices and investing in green technologies to reduce their environmental footprint. The government could also prioritize the implementation of fiscal reforms to boost domestic revenue for development, which would ensure the required funding for supporting sustainable infrastructure development and implement measures for environmental protection. The policy implications are in line with those of previous research that highlights the significance of sustainable development practices and environmental protection measures in reducing the negative impacts of economic activities on the environment.

7 Policy suggestions

First, to promote sustainable economic development and reduce reliance on industries that generate substantial carbon emissions, Bangladesh must broaden the scope of its export markets. However, the country has faced challenges in achieving significant export diversification. The majority of its exports have been primarily targeted toward a select few traditional markets, such as the EU, the United States, Canada, and Japan, with the readymade garments (RMG) sector dominating the export composition. The heavy reliance on the RMG sector for exports has made the economy vulnerable to external shocks and changes in market demand, highlighting the importance of expanding the range of exports. To address this matter, the government of Bangladesh may consider prioritizing the expansion of its export markets. This can be achieved by directing investments toward industries with high potential and leveraging the country's competitive strengths. For example, the government could focus on expanding its manufacturing export base by attracting FDIs and establishing regional production networks, taking inspiration from successful diversification policies implemented by countries like Vietnam. Bangladesh can gain valuable insights from Vietnam's successful transition from agriculture to industries like textiles, electronics, and equipment production. Furthermore, Bangladesh has the potential to benefit significantly from the adoption of a well-rounded approach to diversifying its export portfolio. This approach would involve creating trade agreements with other countries, expanding the range of products it sells internationally, and prioritizing industries where it has a competitive advantage. The country's position on the economic complexity index has consistently lagged behind its counterparts, indicating the potential for diversifying its range of exports. Expanding exports in the industries of leather and footwear, plastics, and light engineering have been identified as areas of great potential for Bangladeshi goods to enter global markets. Bangladesh should consider expanding its production structure to reduce its vulnerability to natural disasters and fluctuations in global demand while also diversifying its exports. In order to accomplish this, it is crucial to enhance the utilization of local resources, allocate funds toward fostering innovation and technological progress, and modernize the policy approach to align with contemporary standards. The nation's involvement in emerging industries, such as electronics and pharmaceuticals, showcases its ability to diversify its economy and adapt to changing circumstances. The World Bank Group has emphasized the importance of diversifying Bangladesh's exports beyond the textile industry to create more job opportunities and sustain economic growth. The country's heavy reliance on the garment industry has made it vulnerable to various challenges, including a lack of skilled workers, inefficient transportation systems, and uncertainty regarding entering the market. Exploring new avenues for exports is observed as a potential solution to address Bangladesh's employment challenges and economic hardships.

Second, suggesting investment in renewable energy and energy-efficient practices is a crucial policy recommendation for the government of Bangladesh to mitigate the negative impacts of infrastructure development on the environment. The nation's energy industry heavily relies on fossil fuels, leading to substantial carbon emissions and ecological consequences. Therefore, directing resources toward renewable energy sources like solar, wind, and hydroelectric power could effectively decrease the country's carbon emissions and promote sustainable economic growth. Utilizing energy-efficient methods and renewable energy sources can significantly reduce energy consumption and carbon emissions. The government has the power to support energy-efficient architectural designs, like green buildings, and encourage the use of energy-efficient appliances and equipment, which has the potential to reduce energy consumption and encourage the use of sustainable development practices. Investing in renewable energy and adopting energy-efficient techniques could have positive spillover effects for other nations. It would be beneficial for other developing nations to learn from Bangladesh's experience and adopt similar strategies to promote sustainable development practices and reduce carbon emissions. Developed nations could benefit from Bangladesh's investment in renewable energy and energy-efficient practices as it would help reduce their reliance on fossil fuels and promote sustainable economic growth. In order to mitigate the negative impact of infrastructure development on the environment, the government of Bangladesh must prioritize investing in renewable energy and adopting energy-efficient practices. This approach holds promise for creating a positive impact on other nations as it promotes the adoption of sustainable development practices and helps reduce carbon emissions.

Third, ensuring strict adherence to rigorous environmental standards is crucial to ensuring that infrastructure development and industrial operations are conducted in an environmentally sustainable manner. Despite initial concerns about the impact of strict environmental regulations on businesses, studies have shown that these rules can actually drive TI and result in a decrease in pollution. Implementing more stringent environmental regulations could encourage a reduction in pollutants, especially among businesses with a significant impact on pollution. As a result, there could be a reduction in the release of harmful substances and a decrease in water consumption. Despite the progress made in environmental standards, the issue of noncompliance with environmental rules continues to persist. Governments must place infrastructure at the forefront of their climate action agenda and thoroughly evaluate the design, execution, and oversight of infrastructure to ensure its compatibility with a low-emission and resilient future. Therefore, it is crucial to implement more stringent environmental regulations to safeguard ES and mitigate the negative impacts of infrastructure development and industrial activity on greenhouse gas emissions and pollution.

8 Conclusion

This study examined the complex link between economic development, remittances, technological innovation, and ES in Bangladesh from 1980 to 2020. The research presented a complete examination of these determinants using a range of rigorous econometric approaches, including the EKC, unit root testing, co-integration analysis, and advanced time-series modeling using ARDL. The data demonstrated that economic expansion originally increased carbon emissions and ecological deterioration, but beyond a certain point, additional economic progress was connected with environmental improvements. This is consistent with the EKC theory, which states that although early stages of economic development might damage the environment, mature phases provide ecological benefits. A 10% increase in economic growth (Y) first increased CO_2 emissions and ecological degradation, but additional growth led to a decrease in both negative effects, supporting the inverted U-shaped connection suggested by the EKC framework.

REM were shown to have a substantial effect on ES. Increased remittance inflows resulted in increased carbon emissions and environmental degradation, with a 10% increase in remittances increasing long-term CO_2 emissions by 1.531% and ecological degradation by 0.725%. This shows that remittances, although economically advantageous, typically lead to increased consumption and energy usage, hence increasing environmental deterioration. However, the analysis indicated a U-inverted connection between REM inflows and environmental deterioration, suggesting that additional increases in remittances might contribute to environmental sustainability. TI has been proved to have an important influence in lowering carbon emissions and increasing ecological stability. A 1% increase in technical innovation might lower long-term CO_2 emissions by 0.1724% while improving ecological stability by 0.1407%. These results highlight the need of promoting technical breakthroughs to meet sustainable development objectives. Export earnings and IFD were both considered. The research discovered a negative relationship between export revenues and environmental sustainability in both long- and short-run analyses. A 10% increase in export revenues might increase CO_2 emissions by 0.913% and ecological degradation by 1.229% in the long term. Similarly, infrastructure growth has negative consequences on environmental quality, with a 10% increase in infrastructure expenditure resulting in greater CO_2 emissions by 1.229% and ecological footprint by 0.533%. The relevance of these discoveries stems from their policy consequences. Bangladeshi policymakers must examine the environmental impact of remittances and encourage technical innovation to ensure long-term prosperity. The research offers useful information that may help guide the creation of policies for balancing economic growth and environmental preservation. Bangladesh may achieve its sustainable development objectives by utilizing technological innovation and implementing sustainable practices in remittance use, export profits, and infrastructure development.

Data availability statement

Publicly available datasets were analyzed in this study. These data can be found at: https://databank.worldbank.org/source/world-development-indicators#.

Author contributions

XY: Conceptualization, Methodology, Formal analysis, Writing–original draft, Writing–review and editing, Supervision. MQ: Data Curation, Software, Investigation, Writing–original draft, Visualization, Validation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abdullah-Al-Mahbub, M., Islam, ARMT, Almohamad, H., Al Dughairi, A. A., Al-Mutiry, M., and Abdo, H. G. (2022). Different forms of solar energy progress: the fast-growing eco-friendly energy source in Bangladesh for a sustainable future. *Energies* 15, 6790. doi:10.3390/en15186790

Ahmad, M., Ul Haq, Z., Khan, Z., Khattak, S. I., Ur Rahman, Z., and Khan, S. (2019a). Does the inflow of remittances cause environmental degradation? Empirical evidence from China. *Econ. Research-Ekonomska Istraživanja* 32, 2099–2121. doi:10.1080/1331677x.2019.1642783

Ahmad, W., Ozturk, I., and Majeed, M. T. (2022). How do remittances affect environmental sustainability in Pakistan? Evidence from NARDL approach. *Energy* 243, 122726. doi:10.1016/j.energy.2021.122726

Ahmed, F., Basak, B., Chakraborty, S., Karmokar, T., Reza, A. W., Arefin, M. S., et al. (2022a). "Sustainable and profitable IT infrastructure of Bangladesh using green IT," in International conference on intelligent computing and optimization. Springer, 185–199.

Ahmed, Z., Caglar, A. E., and Murshed, M. (2022b). A path towards environmental sustainability: the role of clean energy and democracy in ecological footprint of Pakistan. *J. Clean. Prod.* 358, 132007. doi:10.1016/j.jclepro.2022.132007

Akter, S. (2016). Remittance inflows and its contribution to the economic growth of Bangladesh. *J Mod. Soc. Cult. Res., Niigata Univ. Graduate Sch. Contemp. Soc. Cult.* 62, 215–245.

Ali, B., Abdulahi, U., Bani, Y., Ismail, N. W., and Rosland, A. (2022). Does financial development mediate the impact of remittances on sustainable human capital investment? New insights from SSA countries. *Cogent Econ. and Finance* 10 (1). doi:10.1080/23322039.2022.2078460

Aloqab, A., Hu, W., Al-Sharafi, M., AL-Barakani, A., Elayah, W., and Munir, S. (2023). The impact of technological innovation and financial development on environmental pollution in gulf cooperation council – a linear and nonlinear ARDL approach. *Environ. Sci. Pollut. Res.* 30, 114294–114309. doi:10.1007/s11356-023-30372-4

Amiri, A., and Ventelou, B. (2012). Granger causality between total expenditure on health and GDP in OECD: evidence from the Toda–Yamamoto approach. *Econ. Lett.* 116, 541–544. doi:10.1016/j.econlet.2012.04.040

Amit, S., and Kafy, A. A. (2024). Addressing the dollar crisis by investigating underlying causes, effects, and strategic solutions in emerging economies. *Res. Glob.* 8, 100187. doi:10.1016/j.resglo.2023.100187

Apergis, N., Can, M., Gozgor, G., and Lau, C. K. M. (2018). Effects of export concentration on CO(2) emissions in developed countries: an empirical analysis. *Environ. Sci. Pollut. Res. Int.* 25, 14106–14116. doi:10.1007/s11356-018-1634-x

Artmann, M., Kohler, M., Meinel, G., Gan, J., and Ioja, I. C. (2019). How smart growth and green infrastructure can mutually support each other—a conceptual framework for compact and green cities. *Ecol. Indic.* 96, 10–22. doi:10.1016/j.ecolind.2017.07.001

Awad, A., Mallek, R. S., Ozturk, I., and Abdalla, Y. A. (2023). Infrastructure Development's role in environmental degradation in sub-Saharan Africa: impacts and transmission channels. *J. Clean. Prod.* 414, 137622. doi:10.1016/j.jclepro.2023.137622

Awaworyi, C. S., Inekwe, J., Smyth, R., and Zhang, X. (2019). R&D intensity and carbon emissions in the G7: 1870–2014. *Energy Econ.* 80, 30–37. doi:10.1016/j.eneco.2018.12.020

Bagadeem, S., Gohar, R., Wong, W.-K., Salman, A., and Chang, B. H. (2024). Nexus between foreign direct investment, trade openness, and carbon emissions: fresh insights using innovative methodologies. *Cogent Econ. and Finance* 12, 2295721. doi:10.1080/23322039.2023.2295721

Baky, M. A. H., Rahman, M. M., and Islam, A. S. (2017). Development of renewable energy sector in Bangladesh: current status and future potentials. *Renew. Sustain. Energy Rev.* 73, 1184–1197. doi:10.1016/j.rser.2017.02.047

Balcilar, M., Uzuner, G., Nwani, C., and Bekun, F. V. (2023). Boosting energy efficiency in Turkey: the role of public–private partnership investment. *Sustainability* 15, 2273. doi:10.3390/su15032273

Balsalobre-Lorente, D., Topaloglu, E. E., Nur, T., and Evcimen, C. (2023). Exploring the linkage between financial development and ecological footprint in APEC countries: a novel view under corruption perception and environmental policy stringency. *J. Clean. Prod.* 414, 137686. doi:10.1016/j.jclepro.2023.137686

Bayer, C., and Hanck, C. (2013). Combining non-cointegration tests. *J. Time Ser. Analysis* 34, 83–95. doi:10.1111/j.1467-9892.2012.00814.x

Boyce, J. (2019). *Economics for people and the planet: inequality in the era of climate change*. Anthem Press.

Brown, L., McFarlane, A., Campbell, K., and Das, A. (2020). Remittances and CO2 emissions in Jamaica: an asymmetric modified environmental Kuznets curve. *J. Econ. Asymmetries* 22, e00166. doi:10.1016/j.jeca.2020.e00166

Çatık, A. N., Bucak, Ç., Ballı, E., Manga, M., and Destek, M. A. (2024). How do energy consumption, globalization, and income inequality affect environmental quality across growth regimes? *Environ. Sci. Pollut. Res.* 31, 10976–10993. doi:10.1007/s11356-023-31797-7

Chen, L., Ye, W., Huo, C., and James, K. (2020). Environmental regulations, the industrial structure, and high-quality regional economic development: evidence from China. *Land* 9, 517. doi:10.3390/land9120517

Chhabra, M., Giri, A. K., and Kumar, A. (2023). Do trade openness and institutional quality contribute to carbon emission reduction? Evidence from BRICS countries. *Environ. Sci. Pollut. Res.* 30, 50986–51002. doi:10.1007/s11356-023-25789-w

Choumert, J., Motel, P. C., and Millock, K. (2015). Climate change mitigation and adaptation in developing and transition countries: introduction to the special issue introduction to the special issue. *Environ. Dev. Econ.* 20: 425–433. doi:10.1017/s1355770x15000145

Chunyu, L., Zain-ul-Abidin, S., Majeed, W., Raza, S. M. F., and Ahmad, I. (2021). RETRACTED ARTICLE: the non-linear relationship between carbon dioxide emissions, financial development and energy consumption in developing European and Central Asian economies. *Environ. Sci. Pollut. Res.* 28, 63330–63345. doi:10.1007/s11356-021-15225-2

Cutcu, I., Beyaz, A., Gerlikhan, S. G., and Kilic, Y. (2023). Is ecological footprint related to foreign trade? Evidence from the top ten fastest developing countries in the global economy. *J. Clean. Prod.* 413, 137517. doi:10.1016/j.jclepro.2023.137517

Damrah, S., Satrovic, E., and Shawtari, F. A. (2022). How does financial inclusion affect environmental degradation in the six oil exporting countries? The moderating role of information and communication technology. *Front. Environ. Sci.* 10. doi:10.3389/fenvs.2022.1013326

Das, N., and Dutta, P. (2023). Analysing the relationship between public infrastructures and economic growth in Assam. *J. Infrastructure Dev.*, 09749306231163975.

Dash, R. K., Gupta, D. J., and Singh, N. (2024). Remittances and environment quality: asymmetric evidence from south asia. *Res. Glob.* 8, 100182. doi:10.1016/j.resglo.2023.100182

Derindag, O. F., Maydybura, A., Kalra, A., Wong, W. K., and Chang, B. H. (2023). Carbon emissions and the rising effect of trade openness and foreign direct investment: evidence from a threshold regression model. *Heliyon* 9, e17448. doi:10.1016/j.heliyon.2023.e17448

de Vries, G. J., and Ferrarini, B. (2017). What accounts for the growth of carbon dioxide emissions in advanced and emerging economies? The role of consumption, technology and global supply chain participation. *Ecol. Econ.* 132, 213–223. doi:10.1016/j.ecolecon.2016.11.001

Dilanchiev, A., Sharif, A., Ayad, H., and Nuta, A. C. (2024). The interaction between remittance, FDI, renewable energy, and environmental quality: a panel data analysis for the top remittance-receiving countries. *Environ. Sci. Pollut. Res.* 31, 14912–14926. doi:10.1007/s11356-024-32150-2

Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey. *Ecol. Econ.* 49, 431–455. doi:10.1016/j.ecolecon.2004.02.011

Dogan, B., Madaleno, M., Tiwari, A. K., and Hammoudeh, S. (2020). Impacts of export quality on environmental degradation: does income matter? *Environ. Sci. Pollut. Res.* 27, 13735–13772. doi:10.1007/s11356-019-07371-5

Fang, J., Gozgor, G., Lu, Z., and Wu, W. (2019). Effects of the export product quality on carbon dioxide emissions: evidence from developing economies. *Environ. Sci. Pollut. Res.* 26, 12181–12193. doi:10.1007/s11356-019-04513-7

Galván, A., Haas, J., Moreno-Leiva, S., Osorio-Aravena, J. C., Nowak, W., Palma-Benke, R., et al. (2022). Exporting sunshine: planning South America's electricity transition with green hydrogen. *Appl. Energy* 325, 119569. doi:10.1016/j.apenergy.2022.119569

Galvan, L. P. C., Bhatti, U. A., Campo, C. C., and Trujillo, R. A. S. (2022). The nexus between CO2 emission, economic growth, trade openness: evidences from middle-income trap countries. *Front. Environ. Sci.* 10. doi:10.3389/fenvs.2022.938776

Gao, J., Gao, F., Yin, B., and Zhang, M. (2021). International trade as a double-edged sword: the perspective of carbon emissions. *Front. Energy Res.* 9. doi:10.3389/fenrg.2021.764914

Giang, D. T. H., and Sui, P. L. (2011). Role of construction in economic development: review of key concepts in the past 40 years. *Habitat Int.* 35, 118–125. doi:10.1016/j.habitatint.2010.06.003

Hao, Y. (2022). The relationship between renewable energy consumption, carbon emissions, output, and export in industrial and agricultural sectors: evidence from China. *Environ. Sci. Pollut. Res.* 29, 63081–63098. doi:10.1007/s11356-022-20141-0

Haque, M. N., Saroar, M., Fattah, M. A., and Morshed, S. R. (2020). Public-Private Partnership for achieving sustainable development goals: a case study of Khulna, Bangladesh. *Public Adm. Policy* 23, 283–298. doi:10.1108/pap-04-2020-0023

Haque, M. N., Saroar, M., Fattah, M. A., and Morshed, S. R. (2022). Environmental benefits of blue ecosystem services and residents' willingness to pay in Khulna city, Bangladesh. *Heliyon* 8, e09535. doi:10.1016/j.heliyon.2022.e09535

Hasan, M. A., Mahjabin, T., Hossain, M. A., Kibria, M. G., and Haseeb, M. (2023). Towards green economy and sustainable development in Bangladesh: assessing the role of social and environmental indicators. *Environ. Sci. Pollut. Res. Int.* 30, 110324–110339. doi:10.1007/s11356-023-30060-3

Hasan, M. B., Ali, M. S., Uddin, G. S., Mahi, M. A., Liu, Y., and Park, D. (2022). Is Bangladesh on the right path toward sustainable development? An empirical exploration of energy sources, economic growth, and CO2 discharges nexus. *Resour. Policy* 79, 103125. doi:10.1016/j.resourpol.2022.103125

Hasan, M. K., Shahriar, A., and Jim, K. U. (2019). Water pollution in Bangladesh and its impact on public health. *Heliyon* 5, e02145. doi:10.1016/j.heliyon.2019.e02145

Hasnat, G., Kabir, M. A., and Hossain, M. A. (2018). Major environmental issues and problems of South Asia, particularly Bangladesh. *Handb. Environ. Mater. Manag.*, 1–40. doi:10.1007/978-3-319-58538-3_7-1

Hassan, T., Song, H., and Kirikkaleli, D. (2022). International trade and consumption-based carbon emissions: evaluating the role of composite risk for RCEP economies. *Environ. Sci. Pollut. Res. Int.* 29, 3417–3437. doi:10.1007/s11356-021-15617-4

Henk, L. M. K. (1999). Maneuvering space for environmental policy in LDC primary export sectors. *J. Dev. Areas* 33, 515–530.

Hoque, M. Z., Cui, S., Xu, L., Islam, I., Tang, J., and Ding, S. (2019). Assessing agricultural livelihood vulnerability to climate change in coastal Bangladesh. *Int. J. Environ. Res. Public Health* 16, 4552. doi:10.3390/ijerph16224552

Hosan, S., Rahman, M. M., Karmaker, S. C., Sen, K. K., Chapman, A. J., and Saha, B. B. (2023). Transformation of ecological footprint through financial development and technological innovation. *Clean Technol. Environ. Policy* 25, 3363–3380. doi:10.1007/s10098-023-02590-4

Hossain, M., and Islam, M. (2022). Use of artificial intelligence for precision agriculture in Bangladesh. *J. Agric. Rural Res.* 6, 81–96.

Huang, J., and Wu, Z. (2022). Impact of environmental regulations on export trade-empirical analysis based on zhejiang province. *Int. J. Environ. Res. Public Health* 19, 12569. doi:10.3390/ijerph191912569

Huang, S. Z., Sadiq, M., and Chien, F. (2023). The impact of natural resource rent, financial development, and urbanization on carbon emission. *Environ. Sci. Pollut. Res. Int.* 30, 42753–42765. doi:10.1007/s11356-021-16818-7

Invernizzi, D. C., Locatelli, G., Velenturf, A., Love, P. E., Purnell, P., and Brookes, N. J. (2020). Developing policies for the end-of-life of energy infrastructure: coming to terms with the challenges of decommissioning. *Energy Policy* 144, 111677. doi:10.1016/j.enpol.2020.111677

Islam, M. M., Irfan, M., Shahbaz, M., and Vo, X. V. (2022). Renewable and non-renewable energy consumption in Bangladesh: the relative influencing profiles of economic factors, urbanization, physical infrastructure and institutional quality. *Renew. energy* 184, 1130–1149. doi:10.1016/j.renene.2021.12.020

Islam, M. R. (2019). Economic growth rates and exports of Bangladesh: the bengal tiger? *South Asia Res.* 39, 285–303. doi:10.1177/0262728019861760

Islam, M. S. (2022). Do personal remittances cause environmental pollution? Evidence from the top eight remittance-receiving countries. *Environ. Sci. Pollut. Res.* 29, 35768–35779. doi:10.1007/s11356-021-18175-x

Jiao, Z., Sharma, R., Kautish, P., and Hussain, H. I. (2021). Unveiling the asymmetric impact of exports, oil prices, technological innovations, and income inequality on carbon emissions in India. *Resour. Policy* 74, 102408. doi:10.1016/j.resourpol.2021.102408

JinRu, L., Qamruzzaman, M., Hangyu, W., and Kler, R. (2023). An assessment of the symmetric and asymmetric impact of Globalization, environmental sustainability on Tourism Development in BRICS nations: mediating role of Good governance. *Front. Environ. Sci.* 11, 190. doi:10.3389/fenvs.2023.1154295

Ju, S., Andriamahery, A., Qamruzzaman, M., and Kor, S. (2023). Effects of financial development, FDI and good governance on environmental degradation in the Arab nation: dose technological innovation matters? *Front. Environ. Sci.* 11. doi:10.3389/fenvs.2023.1094976

Jugurnath, B., Roucheet, B., and Teeroovengadum, V. (2017). Moving to greener pastures: untangling the evidence about fdi and environmental regulation in Eu countries untangling the evidence about fdi and environmental regulation in eu countries. *J. Dev. Areas* 51, 405–415. doi:10.1353/jda.2017.0053

Kabir, Z., and Khan, I. (2020). Environmental impact assessment of waste to energy projects in developing countries: general guidelines in the context of Bangladesh. *Sustain. Energy Technol. Assessments* 37, 100619. doi:10.1016/j.seta.2019.100619

Karasoy, A. (2021). "How do remittances to the Philippines affect its environmental sustainability? Evidence based on the augmented ARDL approach," in *Natural resources forum*. Wiley Online Library, 120–137.

Ke, H., Dai, S., and Yu, H. (2022). Effect of green innovation efficiency on ecological footprint in 283 Chinese Cities from 2008 to 2018. *Environ. Dev. Sustain.* 24, 2841–2860. doi:10.1007/s10668-021-01556-0

Khan, A., Safdar, S., and Nadeem, H. (2023). Decomposing the effect of trade on environment: a case study of Pakistan. *Environ. Sci. Pollut. Res.* 30, 3817–3834. doi:10.1007/s11356-022-21705-w

Li, H.-S., Geng, Y.-C., Shinwari, R., Yangjie, W., and Rjoub, H. (2021). Does renewable energy electricity and economic complexity index help to achieve carbon neutrality target of top exporting countries? *J. Environ. Manag.* 299, 113386. doi:10.1016/j.jenvman.2021.113386

Li, J., and Qamruzzaman, M. (2022). Dose tourism induce Sustainable Human capital development in BRICS through the channel of capital formation and financial development: evidence from Augmented ARDL with structural Break and Fourier TY causality. *Front. Psychol.* 1260.

Li, K., Wang, X., Musah, M., Ning, Y., Murshed, M., Alfred, M., et al. (2022a). Have international remittance inflows degraded environmental quality? A carbon emission mitigation analysis for Ghana. *Environ. Sci. Pollut. Res. Int.* 29, 60354–60370. doi:10.1007/s11356-022-20094-4

Li, K., Wang, X., Musah, M., Ning, Y., Murshed, M., Alfred, M., et al. (2022b). Have international remittance inflows degraded environmental quality? A carbon emission mitigation analysis for Ghana. *Environ. Sci. Pollut. Res.* 29, 60354–60370. doi:10.1007/s11356-022-20094-4

Li, X., and Yang, L. (2023). Natural resources, remittances and carbon emissions: a Dutch Disease perspective with remittances for South Asia. *Resour. Policy* 85, 104001. doi:10.1016/j.resourpol.2023.104001

Li, Z., and Qamruzzaman, M. (2023). Nexus between environmental degradation, clean energy, financial inclusion, and poverty: evidence with DSUR, CUP-fm, and CUP-bc estimation. *Sustainability* 15, 14161. doi:10.3390/su151914161

Lin, J., and Qamruzzaman, M. (2023). The impact of environmental disclosure and the quality of financial disclosure quality, and IT adoption on firm performance: does corporate governance ensure sustainability? *Front. Environ. Sci.* 11, 23. doi:10.3389/fenvs.2023.1002357

Lingyan, M., Qamruzzaman, M., and Adow, A. H. E. (2021). Technological adaption and open innovation in SMEs: an strategic assessment for women-owned SMEs sustainability in Bangladesh. *Sustainability* 13, 2942. doi:10.3390/su13052942

Liu, J., Ghastine, L., Um, P., Rovit, E., and Wu, T. (2021). Environmental exposures and sleep outcomes: a review of evidence, potential mechanisms, and implications. *Environ. Res.* 196, 110406. doi:10.1016/j.envres.2020.110406

Liu, X., Razzaq, A., Shahzad, M., and Irfan, M. (2022). Technological changes, financial development and ecological consequences: a comparative study of developed and developing economies. *Technol. Forecast. Soc. Change* 184, 122004. doi:10.1016/j.techfore.2022.122004

Liu, Y., Poulová, P., Pražák, P., Ullah, F., and Nathaniel, S. P. (2023). Infrastructure development, human development index, and CO2 emissions in China: a quantile regression approach. *Front. Environ. Sci.* 11. doi:10.3389/fenvs.2023.1114977

Luo, Z., Wan, G., Wang, C., and Zhang, X. (2018). Urban pollution and road infrastructure: a case study of China. *China Econ. Rev.* 49, 171–183. doi:10.1016/j.chieco.2017.04.008

Maduekwe, N. I., and Adesina, F. A. (2022). Can remittances contribute to financing climate actions in developing countries? Evidence from analyses of households' climate hazard exposure and adaptation actors in SE Nigeria. *Mitig. Adapt Strateg. Glob. Chang.* 27, 10. doi:10.1007/s11027-021-09987-w

Maki, D. (2012). Tests for cointegration allowing for an unknown number of breaks. *Econ. Model.* 29, 2011–2015. doi:10.1016/j.econmod.2012.04.022

Malec, K., Majune, S. K., Kuzmenko, E., Phiri, J., Nyamoita, R. L. M., Appiah-Kubi, S. N. K., et al. (2023). Energy logistic regression and survival model: case study of Russian exports. *Int. J. Environ. Res. Public Health* 20, 885. doi:10.3390/ijerph20010885

Manga, M., Cengiz, O., and Destek, M. A. (2023). Is export quality a viable option for sustainable development paths of Asian countries? *Environ. Sci. Pollut. Res.* 30, 50022–50045. doi:10.1007/s11356-023-25784-1

Mavrotas, G., and Kelly, R. (2001). Old wine in new bottles: testing causality between savings and growth. *Manch. Sch.* 69, 97–105. doi:10.1111/1467-9957.69.s1.6

Md Qamruzzaman, S. N., and Ananda, B. (2021). Nexus between remittance, financial volatility, trade openness, money supply, and non-performing loan: an application of autoregressive distributed lagged (ARDL) model. *J. Bank. Finance Manag.* 3, 34–54.

Mills, E. (2023). Green Remittances: a novel form of sustainability finance. *Energy Policy* 176, 113501. doi:10.1016/j.enpol.2023.113501

Nandy, D. (2023). "Impact of pollution and economic growth on the Maldives and Bangladesh: interrogative economic development and environmental governance," in *The impact of environmental emissions and aggregate economic activity on industry: theoretical and empirical perspectives*. Emerald Publishing Limited, 249–260.

Nabila, A., Ceci, F., Ahmad, F., and Aftab, J. (2022). Financial development and green innovation, the ultimate solutions to an environmentally sustainable society: evidence from leading economies. *J. Clean. Prod.* 369, 133223. doi:10.1016/j.jclepro.2022.133223

Ng, S., and Perron, P. (2001). Lag length selection and the construction of unit root tests with good size and power. *Econometrica* 69, 1519–1554. doi:10.1111/1468-0262.00256

Numan, U., Ma, B., Aslam, M., Bedru, H. D., Jiang, C., and Sadiq, M. (2023). Role of economic complexity and energy sector in moving towards sustainability in the exporting economies. *Energy Strategy Rev.* 45, 101038. doi:10.1016/j.esr.2022.101038

Ota, L., Chazdon, R. L., Herbohn, J., Gregorio, N., Mukul, S. A., and Wilson, S. J. (2020). Achieving quality forest and landscape restoration in the tropics. *Forests* 11, 820. doi:10.3390/f11080820

Peever, J., and Fuller, P. M. (2016). Neuroscience: a distributed neural network controls REM sleep. *Curr. Biol.* 26, R34–R35. doi:10.1016/j.cub.2015.11.011

Perron, P., and Vogelsang, T. J. (1992). Nonstationarity and level shifts with an application to purchasing power parity. *J. Bus. and Econ. Statistics* 10, 301–320. doi:10.1080/07350015.1992.10509907

Pesaran, M. H., Shin, Y., and Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *J. Appl. Econ.* 16, 289–326. doi:10.1002/jae.616

Qamruzzaman, M. (2023a). Clean energy-led tourism development in Malaysia: do environmental degradation, FDI, Education and ICT matter? *Heliyon* 9, e21779. doi:10.1016/j.heliyon.2023.e21779

Qamruzzaman, M. (2023b). Do environmental and institutional quality attribute to inflows of FDI in Lower-Middle income Nations? Evidences from asymmetric investigation. *GSC Adv. Res. Rev.* 15, 079–104. doi:10.30574/gscarr.2023.15.3.0172

Qamruzzaman, M. (2023c). Does economic policy uncertainty influences personal remittances: evidences from AARDL and NARDL. *World J. Adv. Res. Rev.* 18, 14–34.

Qamruzzaman, M. (2023d). Nexus between environmental qualities, institutional quality and FDI inflows in Lower-income Countries. *World J. Adv. Res. Rev.* 18, 321–345. doi:10.30574/wjarr.2023.18.3.1045

Qamruzzaman, M. (2024). Nexus between foreign direct investment, gross capital formation, financial development and renewable energy consumption: evidence from panel data estimation. *GSC Adv. Res. Rev.* 18, 182–200. doi:10.30574/gscarr.2024.18.1.0011

Qin, X., Li, Y., Lu, Z., and Pan, W. (2020). What makes better village economic development in traditional agricultural areas of China? Evidence from 338 villages. *Habitat Int.* 106, 102286. doi:10.1016/j.habitatint.2020.102286

Qureshi, Z. (2016). Meeting the challenge of sustainable infrastructure: the role of public policy.

Rahman, M., Moazzem, K. G., Chowdhury, M. I., and Sehrin, F. (2014). Connecting South asia and southeast asia: a Bangladesh country study.

Rahman, M. M., Velayutham, E., and Abul Kashem, M. (2023). Are environmental damage and export concentration the major threats for the long-run economic growth in Bangladesh? *PLOS ONE* 18, e0284620. doi:10.1371/journal.pone.0284620

Rahman, M. R. (2015). Causes of biodiversity depletion in Bangladesh and their consequences on ecosystem services. *Am. J. Environ. Prot.* 4, 214–236. doi:10.11648/j.ajep.20150405.13

Raihan, A., Muhtasim, D. A., Farhana, S., Pavel, M. I., Faruk, O., Rahman, M., et al. (2022). Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. *Energy Clim. Change* 3, 100080. doi:10.1016/j.egycc.2022.100080

Raihan, A., Muhtasim, D. A., Farhana, S., Rahman, M., Hasan, M. A. U., Paul, A., et al. (2023). Dynamic linkages between environmental factors and carbon emissions in Thailand. *Environ. Process.* 10, 5. doi:10.1007/s40710-023-00618-x

Rani, T., Wang, F., Rauf, F., Ain, Q. u., and Ali, H. (2023). Linking personal remittance and fossil fuels energy consumption to environmental degradation: evidence from all SAARC countries. *Environ. Dev. Sustain.* 25, 8447–8468. doi:10.1007/s10668-022-02407-2

Razzaq, A., Ajaz, T., Li, J. C., Irfan, M., and Suksatan, W. (2021). Investigating the asymmetric linkages between infrastructure development, green innovation, and consumption-based material footprint: novel empirical estimations from highly resource-consuming economies. *Resour. Policy* 74, 102302. doi:10.1016/j.resourpol.2021.102302

Reza, A. K., Islam, M. S., and Shimu, A. A. (2017). Green industry in Bangladesh: an overview. *Environ. Manag. Sustain. Dev.* 6, 124. doi:10.5296/emsd.v6i2.11027

Roy, H., Alam, S. R., Bin-Masud, R., Prantika, T. R., Pervez, M. N., Islam, M. S., et al. (2022). A review on characteristics, techniques, and waste-to-energy aspects of municipal solid waste management: Bangladesh perspective. *Sustainability* 14, 10265. doi:10.3390/su141610265

Ruba, U. B., and Talucder, M. S. A. (2023). Potentiality of homestead agroforestry for achieving sustainable development goals: Bangladesh perspectives. *Heliyon* 9, e14541. doi:10.1016/j.heliyon.2023.e14541

Sam, C. Y., McNown, R., and Goh, S. K. (2019). An augmented autoregressive distributed lag bounds test for cointegration. *Econ. Model.* 80, 130–141. doi:10.1016/j.econmod.2018.11.001

Serageldin, M. (2016). "Inclusive cities and access to land," in *housing, and services in developing countries*.

Shah, I. A., and Wani, G. A. (2024). Role of governance quality in remittances-poverty relationship: new insights from transition economies. *Foreign Trade Rev.*, 00157325231214045. doi:10.1177/00157325231214045

Shannak, Sd, and Contestabile, M. (2022). Does Qatar face a trade-off between economic growth and CO2 emissions? *Front. Environ. Sci.* 10. doi:10.3389/fenvs.2022.855971

Sharif, A., Kartal, M. T., Bekun, F. V., Pata, U. K., Foon, C. L., and Kılıç Depren, S. (2023). Role of green technology, environmental taxes, and green energy towards sustainable environment: insights from sovereign Nordic countries by CS-ARDL approach. *Gondwana Res.* 117, 194–206. doi:10.1016/j.gr.2023.01.009

Sharma, G. D., Mendy, J., and Shahzad, U. (2022). Editorial: export product quality, renewable energy, and sustainable production. *Front. Environ. Sci.* 10. doi:10.3389/fenvs.2022.1069041

Shin, Y., Yu, B., and Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. *Festschrift honor Peter Schmidt Econ. methods Appl.*, 281–314. doi:10.1007/978-1-4899-8008-3_9

Shittu, O. S., Williams, I. D., and Shaw, P. J. (2021). Global E-waste management: can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges. *Waste Manag.* 120, 549–563. doi:10.1016/j.wasman.2020.10.016

Siddique, M. A. B., Alam, M. K., Islam, S., Diganta, M. T. M., Akbor, M. A., Bithi, U. H., et al. (2020). Apportionment of some chemical elements in soils around the coal mining area in northern Bangladesh and associated health risk assessment. *Environ. Nanotechnol. Monit. and Manag.* 14, 100366. doi:10.1016/j.enmm.2020.100366

Sikder, M. J. U., and Higgins, V. (2017). Remittances and social resilience of migrant households in rural Bangladesh. *Migr. Dev.* 6, 253–275. doi:10.1080/21632324.2016.1142752

Sohel, M. S. I., Mukul, S. A., and Chicharo, L. (2015). A new ecohydrological approach for ecosystem service provision and sustainable management of aquatic ecosystems in Bangladesh. *Ecohydrol. and Hydrobiology* 15, 1–12. doi:10.1016/j.ecohyd.2014.10.001

Song, M., Fisher, R., and Kwoh, Y. (2019). Technological challenges of green innovation and sustainable resource management with large scale data. *Technol. Forecast. Soc. Change* 144, 361–368. doi:10.1016/j.techfore.2018.07.055

Sunge, R., and Mudzingiri, C. (2023). A systematic literature review on migration and remittances in mountainous regions: key takeaways for phuthaditjhaba, free state, South Africa. *Sustainability* 15, 14621. doi:10.3390/su151914621

Su, Q., Shi, X., Su, R., Anees, A., Ali, M. S. E., Brancu, L., et al. (2023). Green finance and foreign direct investment–environmental sustainability nexuses in emerging countries: new insights from the environmental Kuznets curve. *Front. Environ. Sci.* 11. doi:10.3389/fenvs.2023.1074713

Szabo, S., Ahmed, S., Wiśniowski, A., Pramanik, M., Islam, R., Zaman, F., et al. (2022). Remittances and food security in Bangladesh: an empirical country-level analysis. *Public Health Nutr.* 25, 2886–2896. doi:10.1017/s1368980022001252

Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., et al. (2019). Infrastructure for sustainable development. *Nat. Sustain.* 2, 324–331. doi:10.1038/s41893-019-0256-8

Toda, H. Y., and Yamamoto, T. (1995). Statistical inference in vector autoregressions with possibly integrated processes. *J. Econ.* 66, 225–250. doi:10.1016/0304-4076(94)01616-8

Trinh, V. Q., Nguyen, A. T. Q., and Vo, X. V. (2022). Export quality upgrading and environmental sustainability: evidence from the East asia and pacific region. *Res. Int. Bus. Finance* 60, 101632. doi:10.1016/j.ribaf.2022.101632

Uddin, M. J., and Jeong, Y. K. (2021). Urban river pollution in Bangladesh during last 40 years: potential public health and ecological risk, present policy, and future prospects toward smart water management. *Heliyon* 7, e06107. doi:10.1016/j.heliyon.2021.e06107

Ullah, A., Raza, K., and Mehmood, U. (2023). The impact of economic growth, tourism, natural resources, technological innovation on carbon dioxide emission: evidence from BRICS countries. *Environ. Sci. Pollut. Res. Int.* 30, 78825–78838. doi:10.1007/s11356-023-27903-4

Wan, X., Kazmi, S. A. A., and Wong, C. Y. (2022). Manufacturing, exports, and sustainable growth: evidence from developing countries. *Sustainability* 14, 1646. doi:10.3390/su14031646

Wang, K., Rehman, M. A., Fahad, S., and Linzhao, Z. (2023a). Unleashing the influence of natural resources, sustainable energy and human capital on consumption-based carbon emissions in G-7 Countries. *Resour. Policy* 81, 103384. doi:10.1016/j.resourpol.2023.103384

Wang, L., and Li, Y. (2023). Estimation methods and reduction strategies of port carbon emissions-what literatures say? *Mar. Pollut. Bull.* 195, 115451. doi:10.1016/j.marpolbul.2023.115451

Wang, R., Qamruzzaman, M., and Karim, S. (2024). Unveiling the power of education, political stability and ICT in shaping technological innovation in BRI nations. *Heliyon* 10, e30142. doi:10.1016/j.heliyon.2024.e30142

Wang, S., Pan, M., and Wu, X. (2023b). Sustainable development in the export trade from a symbiotic perspective on carbon emissions, exemplified by the case of guangdong, China. *Sustainability* 15, 9667. doi:10.3390/su15129667

Wang, S., Tang, Y., Du, Z., and Song, M. (2020). Export trade, embodied carbon emissions, and environmental pollution: an empirical analysis of China's high- and new-technology industries. *J. Environ. Manag.* 276, 111371. doi:10.1016/j.jenvman.2020.111371

Wang, X., Dong, F., Pan, Y., and Liu, Y. (2022). Transport infrastructure, high-quality development and industrial pollution: fresh evidence from China. *Int. J. Environ. Res. Public Health* 19, 9494. doi:10.3390/ijerph19159494

Wang, X., Lee, Z., and Xie, X. (2023c). Examining the impact of high technology exports on environmental sustainability? An empirical insight. *Econ. Research-Ekonomska Istraživanja* 36, 2195475. doi:10.1080/1331677x.2023.2195475

Wang, Y., Qamruzzaman, M., and Kor, S. (2023d). Greening the future: harnessing ICT, innovation, eco-taxes, and clean energy for sustainable ecology—insights from dynamic seemingly unrelated regression, continuously updated fully modified, and continuously updated bias-corrected models. *Sustainability* 15, 16417. doi:10.3390/su152316417

Williams, M., Abu Alrub, A., and Aga, M. (2022). Ecological footprint, economic uncertainty and foreign direct investment in South Africa: evidence from asymmetric cointegration and dynamic multipliers in a nonlinear ARDL approach. *SAGE Open* 12, 215824402210946. doi:10.1177/21582440221094607

Worika, I. L., and Umofia, N. (2017). The impact of infrastructural development on Nigeria's industrial sector. *Afr. Res. Rev.* 11, 23–30. doi:10.4314/afrrev.v11i3.3

Wu, Y., Chau, K. W., Lu, W., Shen, L., Shuai, C., and Chen, J. (2018). Decoupling relationship between economic output and carbon emission in the Chinese construction industry. *Environ. Impact Assess. Rev.* 71, 60–69. doi:10.1016/j.eiar.2018.04.001

Wu, Z., Yang, L., Chen, Q., and Ye, Q. (2021). The impacts of international trade on global greenhouse gas emissions: a thought experiment based on a novel no-trade analysis. *J. Environ. Manag.* 300, 113836. doi:10.1016/j.jenvman.2021.113836

Xia, C., Qamruzzaman, M., and Adow, A. H. (2022). An asymmetric nexus: remittance-led human capital development in the top 10 remittance-receiving countries: are FDI and gross capital formation critical for a road to sustainability? *Sustainability* 14, 3703. doi:10.3390/su14063703

Xu, S., Qamruzzaman, M., and Adow, A. (2021). Is financial innovation bestowed or a curse for economic sustainably: the mediating role of economic policy uncertainty. *Sustainability* 13, 2391. s Note: MDPI stays neutral with regard to jurisdictional claims in published. doi:10.3390/su13042391

Yang, B., Jahanger, A., and Ali, M. (2021). Remittance inflows affect the ecological footprint in BICS countries: do technological innovation and financial development matter? *Environ. Sci. Pollut. Res.* 28, 23482–23500. doi:10.1007/s11356-021-12400-3

Yin, C., and Qamruzzaman, M. (2024). Empowering renewable energy consumption through public-private investment, urbanization, and globalization: evidence from CS-ARDL and NARDL. *Heliyon* 10, e26455. doi:10.1016/j.heliyon.2024.e26455

Young, C. (2023). Employment and income effects of investments made using the act 13 unconventional natural gas impact fee in Pennsylvania. *Energies* 16, 4437. doi:10.3390/en16114437

Zapata, H. O., and Rambaldi, A. N. (1997). Monte Carlo evidence on cointegration and causation. *Oxf. Bull. Econ. statistics* 59, 285–298. doi:10.1111/1468-0084.00065

Zhang, S., Yang, L., and Cao, S. (2023). Neglected negative consequences of using exports to earn foreign exchange. *Res. Glob.* 7, 100148. doi:10.1016/j.resglo.2023.100148

Zhao, L., and Qamruzzaman, M. (2022). Do urbanization, remittances, and globalization matter for energy consumption in belt and road countries: evidence from renewable and non-renewable energy consumption. *Front. Environ. Sci.* 10. doi:10.3389/fenvs.2022.930728

Zhou, X., Guo, Q., Wang, Y., and Wang, G. (2022). Trade and embodied CO(2) emissions: analysis from a global input-output perspective. *Int. J. Environ. Res. Public Health* 19, 14605. doi:10.3390/ijerph192114605